

PUTTING THE FREEZE ON HFCs:

**A GLOBAL DIGEST OF
AVAILABLE CLIMATE-FRIENDLY
REFRIGERATION AND
AIR-CONDITIONING TECHNOLOGIES**



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COVER IMAGE

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EXECUTIVE SUMMARY

Warming of the climate system is a proven scientific fact. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

Due to the increases in greenhouse gases since the beginning of the industrial revolution, each of the last three decades has been successively warmer at the Earth's surface than any preceding decade on record.¹ Fast-acting mitigation of short-lived climate pollutants, including hydrofluorocarbons (HFCs) is needed to offset increasing severe climate impacts, reduce the risk of passing tipping points for abrupt climate change, and to provide the time needed to control emissions of carbon dioxide (CO₂). Reducing production and use of HFCs, refrigerants with global warming potentials (GWPs)² hundreds to thousands of times higher than CO₂, is the largest, fastest and most cost-effective short-term climate mitigation option currently available and will have a significant effect by 2050.

Fast action to reduce HFCs will virtually eliminate one main class of greenhouse gases (GHGs) and prevent between 90 and 146 billion tonnes of carbon dioxide equivalent (GtCO₂e) emissions by 2050 from a business as usual (BAU) scenario.³ Phasing down HFCs could avoid from 0.35°C to 0.5°C of warming by 2100⁴; which is essential for staying within the long-term international goal of stabilizing global temperature rise at or below 2°C over pre-industrial temperatures by the end of the century.

HFCs have been commercialized to replace chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, which have been or currently are being phased-out under the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) due to their high ozone depleting potential.

Reducing production and use of HFCs, refrigerants with global warming potentials (GWPs) hundreds to thousands of times higher than CO₂, is the largest, fastest and most cost-effective short-term climate mitigation option currently available and will have a significant effect by 2050.

As of 2010, 77 percent of initial transitions in the HCFC phase-out, were to climate-damaging HFCs.⁵ Since the recognition of the damage being caused to the global climate from HFCs, efforts are being made to minimize emissions of HFCs from refrigeration and air-conditioning. However, current and projected consumption and emissions of HFCs are rising exponentially.

A variety of climate friendly, low-GWP refrigerant alternatives to HFCs are currently available including carbon dioxide, air, water, ammonia, hydrocarbons, and some “not-in-kind” technologies such as solar technologies and district cooling.

Fortunately, a variety of climate friendly, low-GWP alternatives to HFCs are currently available, including carbon dioxide, air, water, ammonia, hydrocarbons, and some “not-in-kind” technologies such as solar technologies and district cooling. Using these low-GWP refrigerants is critical to mitigating climate change in the short term. Additionally, companies and countries employing these technologies are discovering substantial improvements in energy efficiency over products and equipment that use HFC refrigerants. Hence, not only are there direct climate benefits by prevention of HFC release but also indirect reduction in emissions from reduced energy consumption.

Although all traditional refrigeration and air-conditioning technologies are based on the same fundamental vapor compression principles, the refrigerant selected, system design, and equipment components used by each end-use differ depending on the application and varying capacity needs. Convenience stores, supermarkets, hypermarkets, warehouses, distribution centers, and refrigerated vehicles all have different refrigeration needs and technical considerations

must be included in decisions to select the correct HFC-free refrigerant for each application. Likewise, houses, commercial buildings, schools, hospitals, and industrial plants, and different climatic regions all have different air-conditioning needs and technical considerations must be included in decisions to select the correct HFC-free refrigerant for each application. The common types of refrigerated equipment include self-contained units (e.g., vending machines, reach-in cases), remote display cases and walk-ins, condensing units, rack systems, packaged systems, central plants, and transport systems (i.e., refrigerated trucks). Common types of air-conditioning systems include factory sealed, single split, multi-split, ducted, chillers, heat pumps, and mobile air conditioners. HFC-free alternatives are commercially available, proven or under rapid development for all of these refrigeration and air-conditioning needs.

This report presents case studies from around the world of commercially available and proven HFC-free technologies for domestic, commercial, industrial and transport refrigeration and air-conditioning equipment. The variety of case studies presented in this digest demonstrate that just like there is no single HFC that can be used in all applications, there is no single alternative that will replace HFCs in all applications; the most appropriate low-GWP technology depends on a variety of factors. In order to remain competitive, companies will have to rapidly transition to the next generation of refrigeration and air-conditioning technologies, which are also critical to combating climate change. Safe, affordable and energy efficient alternatives are already here and the time to transition to natural HFC-free technology is now.

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HUGE ENERGY EFFICIENCY GAINS POSSIBLE

WITH CONVERSIONS TO HFC-FREE TECHNOLOGIES

Refrigeration Equipment

Globally, refrigeration systems use 15 to 20 percent of the world's electricity.¹ In the retailer sector refrigeration accounts for the lion's share of a supermarket's total electricity consumption, and is estimated to represent about 3 to 4 percent of the total sales price of a refrigerated food or drink item.² In the current economic climate, it should come as no surprise that companies are more eager than ever to identify opportunities for energy savings. The following section details some impressive energy savings achieved from transitioning to HFC-free equipment in key sectors. However, it should be noted that optimal system design and regular maintenance are the corner stones of maintaining the energy efficiency gains of the original HFC-free system design.

ENERGY SAVINGS IN COMMERCIAL REFRIGERATION

The rapid roll out of HFC-free systems across the European and South African commercial refrigeration sectors is partly driven by the substantial energy efficiency gains and climate co-benefits obtained from HFC-free systems, in addition to the need to phase-out HFC use. In the case of CO₂, the focus on system design has resulted in state-of-the-art systems, many demonstrating significant energy efficiency gains, therefore cost savings. CO₂ is now the standard refrigerant used in all new supermarkets in Switzerland by law, with Swiss retailers having considerable experience in this technology. It therefore comes as no surprise Swiss retailer Coop Schweiz, which has one quarter of its estate running on transcritical CO₂ systems, plans to have its entire estate converted by 2023. Coop Schweiz

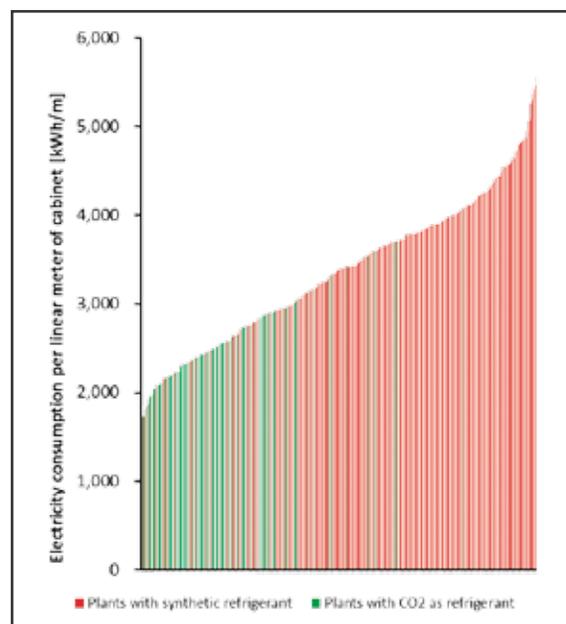


Figure 1: Energy efficiency comparison of HFC refrigerants versus CO₂

Courtesy of Coop Schweiz

is reporting energy savings of approximately 30 percent when compared to systems using fluorinated gas refrigerants, as highlighted by Figure 1. Additional energy savings from heat recovery are not included in this figure.

In the commercial refrigeration sector, water-cooled hydrocarbon systems are also delivering substantial energy savings. British retailer, Waitrose, which plans to have its entire estate HFC-free by 2021, is using this technology and has reported its hydrocarbon systems use approximately 20 percent less energy compared to its traditional HFC systems.

Energy efficiency gains have also been delivered in Asia. Japanese retail giant AEON, which has committed to introduce CO₂ in all its new stores, reports energy savings between 10-30 percent in the stores it has converted to CO₂ since 2009. AEON has announced its transcritical CO₂ systems provide high reliability and high efficiency even in hot and humid climates.³ Similarly, Carrefour's transcritical CO₂ store in Istanbul, Turkey, is reporting energy efficiency improvements of approximately 15 percent.

... rapid progress is improving CO₂ system designs, including the use of parallel compressors which have allowed CO₂ systems to be installed from Turkey to Indonesia to South Africa with substantial energy efficiency savings.

Between 2008 and 2011, German sustainable development agency GIZ-Proklima and South Africa's Environment Ministry assisted South African retailer Pick 'n Pay to install hybrid cascade systems running on CO₂ and ammonia in two of its supermarkets in Cape Town and Johannesburg, which are located in different climate zones (respectively medium and high ambient). The project was driven by a desire to reduce electricity consumption in a country experiencing an energy supply shortage. The two stores were opened in December 2009 and are now fully operational. Energy consumption data from both stores has demonstrated energy savings of 19 to 26 percent compared to traditional HFC systems.⁴

CO₂ systems initially worked better in cooler climates and gained a reputation of not being suitable for use in regions with high ambient temperatures. However, rapid progress is improving CO₂ system design and technology, including the use of parallel compressors, have

allowed CO₂ systems to be installed from Turkey to Indonesia to South Africa with substantial energy efficiency savings realized. CO₂ transcritical systems can now effectively be used in virtually every temperature zone with an energy benefit over traditional synthetic systems.

ENERGY SAVINGS FROM HEAT RECOVERY IN COMMERCIAL REFRIGERATION

The use of heat recovery techniques can significantly reduce energy consumption, running costs and carbon emissions. In any given supermarket, 75 to 90 percent of hot water demand can be supplied from heat recovered from refrigeration, accounting for 2 to 3 percent of the building's total CO₂ emissions.⁵ CO₂ refrigeration systems in particular offer excellent opportunities for heat recovery due to the refrigerant's higher critical pressure.⁶

While it is far from being a standard practice across the industry, several retailers have already implemented innovative heat recovery programs. German retailer Aldi Süd has some striking statistics on the energy savings achieved in its stores that perform heat recovery from refrigeration. Energy savings have been particularly dramatic at its Slovenian (100 percent), Hungarian (100 percent), Swiss (93.8 percent) and Austrian (96.1 percent) sites.⁷ Portuguese retailer Jerónimo Martins is also utilising heat recovery on systems using HFCs, with 343 of its stores equipped with heat exchangers to recover hot air from the cooling systems.⁸

Numerous types of heat exchange equipment are on the market that provide both heating and cooling and are detailed in the following case studies. These heat exchangers deliver dual energy efficiency benefits and are getting greater attention around the world.

Air-conditioning Systems

In the United States, the largest user of air-conditioners in the world, about 185 billion kW hours of energy are used annually on residential cooling.⁹ However, the United States is not the only country using massive amounts of energy on cooling – air conditioner usage is growing exponentially all over the world and particularly

rapidly in developing countries. In 2010 alone, 50 million air-conditioning units were sold in China.¹⁰ Therefore, the need for energy efficient and climate-friendly cooling options is essential, especially in countries with pre-existing electricity shortages such as China and India.

ENERGY SAVINGS IN COMMERCIAL AND DOMESTIC AIR-CONDITIONING

Hydrocarbon-based refrigerants are well suited for use in domestic air conditioners even in warmer climates. Domestic air-conditioners using hydrocarbons are approximately 50 percent more efficient conductors of heat than fluorocarbon refrigerants, while their operating discharge pressures are about 20 percent lower,¹¹ which reduces the work the compressor has to do thereby reducing maintenance costs. These advantages have reportedly led to energy savings of between 17 percent and 35 percent (with average energy savings of 25 percent).¹²

Split systems

Commercial enterprises around the globe have reported noticeable energy savings using hydrocarbon refrigerants in air-cooled split systems including: Watson's Stores, Singapore, recording 24 percent savings; 7-eleven Stores, Kuala Lumpur, recording 24 percent savings; Sumiden Electronics Shah Alam, Malaysia, recording 22 percent savings; and Hosiden Electronics Bangi, Malaysia, recording 25 percent savings.¹³

Room air-conditioners

De'Longhi, an Italian small appliance manufacturer, which has been producing a range of hydrocarbon-based domestic air-conditioners for the European market since 1995, has reported energy savings between 15 percent and 20 percent in its Pinguino PAC W ECO units.¹⁴ Similarly, Indian manufacturer, Godrej's Green Balance range of hydrocarbon-based air-conditioners are reported to save 23 percent more energy than other 5-star products currently on the market.¹⁵ In 2011, Gree, the largest air-conditioner manufacturer in China, opened a 100,000 unit/year production line of hydrocarbon room air-conditioners which have achieved energy efficiency gains of up to 15 percent compared to conventional systems, in addition to much lower hydrocarbon charge sizes dramatically reducing safety concerns.¹⁶



PHOTO: EMMA CLARK, EIA INTERNATIONAL

Commercial enterprises across the globe have reported noticeable energy savings using hydrocarbon refrigerants in air-cooled split systems...

Chillers

Chillers cool water, which is pumped throughout buildings in order to provide cooling in multiple rooms. The technological innovation being seen in CO₂ commercial refrigeration in high ambient climates is being brought to bear on CO₂ chillers and these energy statistics are expected to improve rapidly. Chillers are used in virtually all multi-story buildings with air-conditioning. All alternative HFC-free refrigerants can technically be used as the refrigerant in chillers as the distribution in occupied parts of the building is via cold water/glycol loops. Ammonia and hydrocarbon chillers are already on

the market, with increased energy efficiency of approximately 10 percent in small hydrocarbon chillers and 20 percent for small ammonia chillers. CO₂ is expected to have the same energy efficiency in moderate and 10 percent lower energy efficiency in warm climates. For large centrifugal chillers,¹⁷ water as a refrigerant is an environmentally benign solution, with 5 to 10 percent better energy efficiency than HCFC and HFC chillers.¹⁸

Summary

As the world looks to find energy efficient equipment to reduce energy demand, reduce greenhouse gas emissions and reduce the associated damage to human health and the environment from energy production, converting to HFC-free refrigeration and air-conditioning holds huge and immediate promise. Energy efficient HFC-free equipment is already commercially available in many sectors and more alternatives are under development and being proven on a rapid basis. Producing this next generation refrigeration and air-conditioning equipment presents a multi-billion dollar business opportunity, and simultaneously delivers huge climate benefits and promotes sustainable development.

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DOMESTIC REFRIGERATION

Domestic refrigeration includes appliances such as household refrigerators, freezers, and combined refrigerator/freezer products. Annually more than 100 million domestic refrigerators are manufactured worldwide with storage volumes ranging from 28 to 850 liters (1ft³ to 30 ft³).¹

Typical domestic refrigerators contain a hermetically sealed vapor-compression system with a 50 to 250 watt motor and 50 to 250 grams of refrigerant.² As of 2010, refrigerants used globally in domestic refrigeration consisted of hydrofluorocarbons (HFC-134a) at 60 percent and hydrocarbons (isobutane and propane) at 40 percent.³

Hydrocarbon systems are proving to be superior to traditional systems with HFC-134a as a refrigerant. From a climate impact perspective, hydrocarbons have a negligible 100 year GWP of less than 4, while HFC-134a has an extremely high GWP of 1300.⁴ Domestic hydrocarbon refrigerators and freezers maintain 20 percent lower operating pressures and are 50 percent more efficient at conducting heat, which leads to energy efficiency gains of 30 to 60 percent.^{5,6} Lower operating pressures reduce impacts to pipes, joints, hoses, and fittings, which decreases the likelihood of leaks, enhances the products' useful life and shortens the payback period, resulting in a sensible economic investment by consumers.⁷ It also reduces the amount of noise made by the refrigerator, making HFC-free units more user-friendly.

The global market of domestic refrigerators and freezers is rapidly shifting towards hydrocarbon systems, as nearly all new European, Japanese, and 75 percent of Chinese domestic units use isobutane (HC-600a).⁸ Likewise, countries throughout Asia, Latin America, and southern

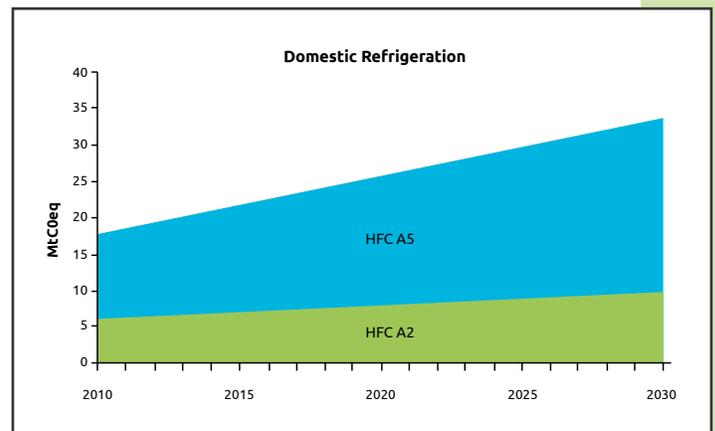


Figure 1: Global BAU HFC Consumption from Domestic Refrigeration (A2 = developed countries A5 = developing countries)¹²

Africa have an increasingly widespread production and adoption of appliances employing hydrocarbons as the refrigerant.⁹ In Korea, LG manufactures more than 11,000 refrigerators per day using hydrocarbon refrigerants and in China three out of the four largest refrigerator manufacturers use hydrocarbon refrigerants.¹⁰ As the transition from HFCs to hydrocarbons continues, it is predicted that by 2020 75 to 80 percent of new domestic refrigerators worldwide will use hydrocarbon refrigerants, rising to 95 percent by 2030.¹¹ However, there is still some growth predicted in HFC consumption in domestic refrigeration (Figure 1).¹² With hydrocarbon

domestic refrigeration gaining in the market around the world, it is possible the predicted HFC growth in domestic refrigeration will not occur. The United States is the only major market with virtually no hydrocarbon refrigerators. The U.S. EPA must approve all refrigerants under its Significant New Alternatives Policy (SNAP) Program before they can be marketed in the U.S.¹³ The EPA in 2011 granted approval for isobutane to be used in domestic refrigerators and freezers, but has imposed a charge size half as large as the rest of the world due to reliance on outdated industrial standards.¹⁴ U.S. domestic refrigerators are restricted to a charge size that cannot exceed 57 grams (same amount of fluid as ten disposable lighters), whereas domestic refrigerators in Europe can have charge sizes up to 150 grams.¹⁵ Efforts are under way to obtain SNAP certification for domestic refrigerators and freezers using the established charge size of propane.

Examples of HFC-free domestic refrigeration can be seen below:

Gorenje Hydrocarbon Refrigerators (Europe, Australia, Asia, Brazil)

The Gorenje Group uses isobutene as the refrigerant in all of its domestic refrigerators and freezers, and reports that they achieve energy savings of up to 50 to 60 percent when compared

to HFC-134a systems.¹⁶ Below is one of Gorenje's highest energy performing refrigerators, the Ion Generation Refrigerator which saves up to 50 percent in energy consumption.¹⁷

Ion Generation Refrigerators use an inverter compressor and consume approximately 168 kWh/year with freezing capacity of 8 kg/24 hours.¹⁸ The inverter compressor technology is built with an innovative sensor system, which tracks user habits and adjusts energy operations accordingly.¹⁹ LED bulbs are used for the interior lighting and the system contains an EcoMode



Gorenje Ion Generation Refrigerators

Image courtesy of Gorenje

energy saving program that minimizes energy use during high-use periods.²⁰ The unit is also built with alarm technology that notifies users if the door is left open, in addition to signifying abnormally high temperatures.²¹

About Gorenje Group: Gorenje Group is a manufacturer of household appliances with sales across Europe, as well as a significant part of Asia, Australia, and Brazil.²² In 2012, Gorenje had 10,895 employees and generated revenue of about U.S. \$1.7 billion.²³

General Electric HC Refrigerators (North America)

General Electric (GE) manufactures an HFC-free, isobutene refrigerator under its luxury Monogram brand. The GE Monogram is the first domestic refrigerator in the United States to use isobutane as a refrigerant.²⁴ The Monogram unit also uses hydrocarbon cyclopentane as an insulating foam-blowing agent.²⁵ The system features a dual compressor and uses LED lighting, which improves the units overall energy efficiency bringing yearly estimated costs to around U.S. \$57.00 at 535 kWh/year.²⁶



GE Monogram
Image courtesy of General Electric

About General Electric: GE is an American multi-national corporation headquartered in Fairfield, Connecticut with operations in more than 160 countries.²⁷ As of 2012, GE had revenue of approximately U.S. \$146 billion and a total of 305,000 employees.²⁸

The Fridge Factory Solar Power Hydrocarbon Refrigerators (Southern Africa)

In 2009, with support from GIZ ProKlima and the National Ozone Unit of Swaziland, Swaziland-based manufacturer Palfridge converted its entire manufacturing facility from HFCs to hydrocarbon refrigerants (isobutane and propane). The company



The Fridge Factory

Image courtesy of The Fridge Factory

now markets two SolarChill prototypes: a vaccine cooler and a commercial refrigerator, both of which are powered by the sun and use hydrocarbons as the refrigerant and foam blowing agent. Efforts are underway by The Fridge Factory to develop domestic refrigerator using SolarChill technology.²⁹ The SolarChill models are equipped with two 90-watt photovoltaic panels that produce energy during the day and store excess energy in a ballast load, which is used during the night and other low light and low energy conditions.³⁰



Commercial Refrigerator

Image courtesy of The Fridge Factory

The Fridge Factory produces 60,000 HFC-free units annually, resulting in up to 1.5 million tonnes of carbon dioxide equivalent (CO₂e) (direct and indirect emissions) abated over a 10-year production period.³¹ The use of an environmentally-friendly hydrocarbon refrigerant along with improved design of equipment has led to energy savings of more than 20 percent compared to conventional technology.³²



Domestic Refrigerator

Image courtesy of The Fridge Factory

The domestic refrigerator, model LS150-Domestic, is designed primarily for rural homesteads and areas with intermittent power supply.³³ The use of a converter increases the versatility of the models, allowing them to be

run off independent power sources such as wind, diesel, biomass and solar.³⁴ The use of independent power sources allows The Fridge Factory to provide refrigeration to areas where there is no existing power grid, and use of wind and solar power mitigates the indirect emissions of CO₂ associated with power generation from traditional sources.

The LS150 Domestic has separate refrigerator and freezer compartments maintaining temperatures from 2° C to -9° C (35° F-48° F).³⁵ The system is preset to achieve optimum cool temperatures in all ambient temperatures and proper insulation techniques allow for the system to maintain cold temperatures for extended periods of low light conditions.³⁶ SolarChill estimates there is a high demand for these units for vaccine storage purposes in developing countries, with one unit capable of meeting the needs of a population of 50,000 people.³⁷

About The Fridge Factory: The Fridge Factory (formerly known as Palfridge), headquartered in Swaziland, is one of the leading refrigeration manufacturers in southern Africa.³⁸

Brastemp Hydrocarbon Refrigerators (Brazil)

Brastemp manufactures home appliances in Brazil and its line of products feature several hydrocarbon refrigerators. Its Inverse Refrigerator Viva 422L (BRE51) is an HFC-free domestic refrigerator using



Brastemp Inverse Viva Refrigerator³⁹

(right) Embraco R600a Compressor

Image courtesy of Shecco

isobutane as a refrigerant, saving over 88 kg of CO₂ emissions per product annually.⁴⁰ The system contains a variable capacity compressor made by Embraco, which enhances energy conservation. The electronic control system increases or decreases the appliances power according to the amount of food stored and reduces energy usage during low use times.⁴¹ These improvements make the Brastemp refrigeration system 33 percent more energy efficient, leading to significant reductions in CO₂ emissions compared to conventional systems.⁴² The refrigerator contains several other environmental improvements, such as: using 80 percent recycled plastic, LED lighting, restriction of hazardous substances manufacturing standards (EU policy banning certain hazardous substances used in manufacturing), and a PROCEL (Programa Nacional de Conservacao de Energia Elctrica) label for its energy efficiency.⁴³

About Brastemp: Headquartered in Sao Paulo, Brastemp (Multibras) is a company under Whirlpool Corporation's portfolio.⁴⁴ In 2013, the Corporation reported annual revenue of U.S. \$19 billion, with 69,000 employees across their 59 manufacturing and technology research centers.⁴⁵

About Embraco: Embraco is based in Joinville, Brazil and has manufactured compressors, components, and cooling systems for national and international markets and currently has products marketed in over 80 countries.⁴⁶ Embraco has the capacity to manufacture over 37 million compressors annually and employs over 9,600 people in six countries, including: Brazil, USA, China, Italy, Slovakia, and Mexico.⁴⁷ Embraco produces an array of energy efficient compressors for domestic and commercial appliances that run on HC-600a or HC-290.⁴⁸ The company has shown that using hydrocarbon refrigerants results in overall 20 percent less energy consumption compared to HFC-404a in addition to quieter running noise.⁴⁹

Midea Hydrocarbon and Air-Cooled Refrigerators (China)

Midea has developed several refrigerators running on HFC-free refrigerants. Its BCD-550WKM refrigerator uses isobutane as its refrigerant. A variable-speed direct current inverter compressor

helps offer substantial energy efficiency savings.⁵⁰ The system has several environmental benefits, including LED lighting, a low refrigerant charge, and a standby mode for low-use periods. Midea reports the refrigerator (550 liters) uses only 1.38 kW/day and only consumes 503 kW/year.⁵¹ Midea also has developed a larger refrigerator (570 liters), the 570WFPMA, which utilizes air as its refrigerant and runs on 1.21 kW/day leading to power consumption of only 442 kW/year.⁵²

About Midea: Since 1980, the Midea Group has manufactured household products and is currently one of the largest manufacturers of electric appliances in China. Midea has operations and production bases throughout China, Vietnam, Belarus, Egypt, Brazil, Argentina and India and its marketing network has branches in the United States, Germany, Japan, Hong Kong, South Korea, Canada, and Russia.⁵⁴

Haier Hydrocarbon Refrigerators (China)

Haier's BCD-579WE hydrocarbon model has a volume of 579 liters (20 ft.³) and uses a reported 1.08 kW/day.⁵⁶ The system has a holiday function, which reduces energy consumption during low-use periods.⁵⁷ The refrigerator features LED lighting, an alarm system for high temperatures, and an air-cooled design that provides for even temperatures throughout the unit.⁵⁸ Haier has a variety of refrigerators of all sizes using hydrocarbon refrigerants.

About Haier: Haier was founded in 1984 and is a global manufacturer of home appliances.



Midea MD-247 Refrigerator⁵³



Haier BCD-579WE Refrigerator⁵⁵

In 2013, Haier's global turnover was U.S. \$28.8 billion.⁵⁹

Bosch Hydrocarbon Refrigerators (Singapore)

Bosch Group has developed a range of hydrocarbon refrigerators for domestic use. The company's BSH Home Appliances office in Singapore sells twenty-

four domestic refrigerator models, including wine coolers that are HFC-free using isobutane as its refrigerant of choice.⁶⁰ Its new line of A++ efficiency refrigerators use up to 40 percent less energy than an equivalent A-rated model.⁶¹

The KIS87AF30 model has an energy efficient rating of A++ with several energy saving technologies, including the holiday mode, which allows a user to switch the appliance to the energy-saving mode when leaving for an extended period of time.⁶³ The unit also has

LED lighting, acoustic warning systems to maximize efficiency, and a SuperCool Function, which rapidly cools food in order to prevent increases in internal temperature.⁶⁴

About Bosch: Bosch Group is headquartered in Munich, Germany and is the third largest manufacturer of home appliances in the world with its line of refrigeration appliances, washing machines, dishwashers, cookers and other consumer products.⁶⁵ In 2013, Bosch Group recorded U.S. \$64.1 million in sales revenue.⁶⁶

Arcelik Hydrocarbon Refrigerators (Turkey)

Arcelik produces and markets durable goods, components, consumer electronics and after-sale services.⁶⁷ In Turkey, Arçelik was the first company to introduce a refrigerator with A+++ energy efficiency, which it reports is the world's most efficient no-frost refrigerator.⁶⁸

The 2488 CNGY A+++ refrigerator runs on isobutane with energy efficiency improvements of more than 40 percent compared to class A refrigerators.⁶⁹ The system has an electronic climate control system that helps maintain stable temperatures with freezing capacity of 6 kg/24 hours and a total volume of 538 liters (19 ft³).⁷⁰ The system is well insulated and claims to maintain cool temperatures for up to 27 hours in the event of a power outage.⁷¹

About Arçelik: Founded in 1955, Arçelik is an appliance manufacturer based in Istanbul, Turkey that sells its products in over 100 countries.⁷³ The company operates production plants in Russia, Romania, South Africa, China and Turkey with a total of over 24,000 employees.⁷⁴

Blupura Italy Hydrocarbon Water Dispensers (Europe, U.S.)

Blupura is the world's first producer of naturally refrigerated water-coolers.⁷⁵ The Italian company manufacturer uses propane and isobutane compressors to chill water in a number of its dispenser models, reporting that use of hydrocarbon refrigerants achieves energy savings of up to 75 percent.⁷⁶ Blupura uses hydrocarbons to chill, still and carbonate water for a range of products suitable for restaurant, office, hospital, school and home use.⁷⁷

About Blupura Italy: As of 2014, Blupura Italy exported a significant share of its products with exports contributing 80 percent of its annual sales.⁷⁸ In February 2014, Blupura USA Inc. was founded due to increased demand of Blupura water coolers in the U.S. market.⁷⁹



Arcelik 5088 A+++ Refrigerator⁷²



Bosch KIS87AF30 Refrigerator⁶²



Blupura Water Cooler
Image courtesy of Blupura

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INDUSTRIAL REFRIGERATION

Industrial refrigeration is used in multiple sectors, including chemicals, and plastics manufacturing; petroleum production; food production and processing; cold-storage; sports and leisure facilities; agricultural storage; and mining processes.¹

Industrial refrigeration has used HFC-free technologies extensively for more than 150 years. While 90 percent of industrial refrigeration uses natural refrigerants in developed countries, HCFC-22 and HFC-404a are used in approximately 40 percent of industrial refrigeration systems in developing countries.² However, in light of the recent revision of the EU F-gas Regulation and movement to phase-out HFCs in the Montreal Protocol, an even greater percentage of companies globally are turning to energy-efficient, cost-effective HFC-free refrigerant solutions in industrial refrigeration. Ammonia systems are generally at least 15 percent more energy efficient than their HFC counterparts.³

Industrial refrigeration systems consist of rack systems or central plants⁴ with refrigeration capacities ranging from 10 kW to 10 MW and about 75 percent of installed capacity in the food sector and 25 percent in industrial processes and leisure.⁵ Rack systems are common in distribution centers and are comprised of pre-manufactured racks that contain multiple compressors and other components that are connected to a remote condenser and linked to display cases and walk-in coolers through a network of piping.⁶ Centralized plants are large refrigeration systems that are commonly used in refrigerated warehouses and distribution centers.⁷ In central plants, evaporators are suspended from the ceiling in the refrigerated space or mounted in outdoor enclosures on the roof of the building and are coupled to multiple

compressors and condensers.⁸ Commonly used designs in rack systems and central plants are indirect design and cascade design.⁹

Indirect design uses two refrigerant fluids: a primary refrigerant and a secondary circulating fluid (the coolant). The primary refrigerant (most commonly ammonia) is used in the part of the

... an even greater percentage of companies globally are turning to energy-efficient, cost-effective HFC-free refrigerant solutions in industrial refrigeration.

refrigeration system that is located entirely in the machinery room or outside of the building to cool the secondary fluid (e.g. glycol, water, or brine), which is then circulated throughout the occupied portion of the building.¹⁰

Cascade design consists of two independent refrigeration systems that share a common heat exchanger.¹¹ The heat exchanger acts as the low temperature refrigerant evaporator.¹² Each component of a cascade design uses a different refrigerant that is most suitable for the given temperature range.¹³ HFC-free cascade systems

are typically comprised of ammonia and CO₂, while propane (HC-290) and CO₂ are also seen.

HFC-free industrial systems primarily consist of ammonia/glycol systems or cascade systems that use CO₂/ammonia or CO₂/propane. Ammonia has remained the refrigerant of choice dating back to the beginning of industrial refrigeration and is widely used in industrial cold storage systems.¹⁴ Many advantages have contributed to the popularity of ammonia for industrial uses, which include ozone depletion potential (ODP) and zero GWP, less required mass flow due to high latent heat, minimal pressure losses in connecting piping and low reactivity with refrigeration lubricants.¹⁵ As end-users come under increasingly stringent safety regulations and the uses of ammonia are expanded to small industrial and commercial settings, there has been dramatic redesign of ammonia systems to significantly reduce ammonia refrigerant charge sizes.

Cascade systems can provide both medium and low temperature cooling with significantly smaller charge sizes.¹⁶ Along with decreasing ammonia charge sizes, cascade systems using CO₂/ammonia are more cost-effective than traditional systems with synthetic refrigerants (HFC, HCFC) and have substantially lower operation and maintenance costs particularly in low temperature applications.¹⁷ Cascade systems in industrial refrigeration have several more benefits, such as reduced costs of refrigerant,

reduction of the low stage compressor size and reductions in the pipe sizes on the low side.¹⁸

The refinement of large and medium sized cascade CO₂/ammonia refrigeration systems has facilitated the change to HFC-free technologies. Under a business as usual scenario, HFC systems in industrial refrigeration are predicted to rise substantially (Figure 1).¹⁹ However, the advent of economically and environmentally superior alternative technologies that are available now with significantly smaller charge sizes and dual cascade systems so that the ammonia or hydrocarbons are not circulated into occupied spaces has increased the use of HFC-free technologies and should alter this prediction.

Below are some case studies of such HFC-free technologies for industrial refrigeration:

Nestle Cascade CO₂/Ammonia Plant (Thailand)

Nestle's plant in Bangkok installed a 6 MW cascade CO₂/ammonia refrigeration system manufactured by Axima Refrigeration of France in 2012.²¹ The system achieves a 13 percent energy savings when compared to conventional cascade CO₂/ammonia systems – making it far more efficient than an HFC system.²² This energy efficiency is achieved by combining heat recovery processes with energy saving solutions, such as variable speed drive compressors, high efficiency motors, increased temperature level for air conditioning, fans with high efficiency for air heat exchangers, and the use of CO₂ refrigerated brine instead of monoethylene glycol.²³ In comparison to conventional HFC-404a units, the new system is reported to reduce direct emissions by 1,905 tonnes of CO₂ equivalent (tCO₂e) per year.²⁴



Nestle²⁰

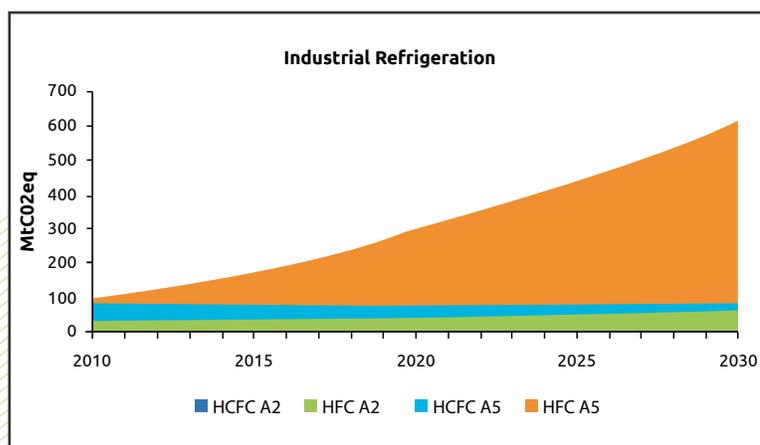


Figure 1: Global BAU Consumption of HCFCs and HFC from Industrial Refrigeration
(A2 = developed countries A5 = developing countries)¹⁹

Nestle: Nestle, headquartered in Switzerland, is a worldwide food company with a distribution network throughout the globe.²⁵ Nestle has several cold storage facilities that utilize cascade CO₂/ammonia systems.²⁶ In 2012, Nestle employed 339,000 people and had revenue of U.S. \$92.18 billion.²⁷

Axima Refrigeration: Axima Refrigeration, based in France, was founded in 2001 as a result of a merger of several refrigeration companies and is a subsidiary of GDF Suez.²⁸ Axima provides service and installations in industrial and commercial refrigeration, including installations for Carrefour, Lidl, and many other supermarkets.²⁹ Axima has 1,350 employees and revenue of U.S. \$320 million as of 2012.³⁰

USCS Cascade CO₂/Ammonia Cold Storage System (U.S.)

United States Cold Storage (USCS) installed a cascade CO₂/ammonia system in its 1.3 million m² (14 million ft²) warehouse in Fresno, California in 2013, claiming it to be one of the industry's most



United States Cold Storage in Fresno, CA³¹

energy-efficient cascade systems installed at the time with 5.8 percent efficiency improvements compared to a conventional indirect ammonia system.³² Efficiencies are found in the part load performance of the reciprocating compressors used on the low side (CO₂).³³ USCS currently has six warehouses that use cascade CO₂/ammonia systems and all six maintain temperatures within -3°F to -8°F (-19°C to -22°C) in the storage freezers, 32°F to 35°F (0°C to 2°C) in the refrigerated storage rooms and 38°F to 40°F (3°C to 4°C) on the docks.³⁴ Through the use of cascade CO₂/ammonia systems at its warehouses, significant energy efficiency gains have been made possible. In the U.S. ammonia is used in over 95 percent of industrial refrigeration systems for

food and beverage processing and storage.³⁵

About United States Cold Storage: USCS has been providing refrigerated storage since 1889 and today is one of the leading public refrigerated warehouse operators in the U.S. with 35 facilities covering nearly 5.66 million m³ (200 million ft³) of storage space across the US.³⁶ USCS has integrated cascade CO₂/ammonia systems in several of its warehouses with over a quarter of its refrigerated warehouse space using cascade systems.³⁷ As of 2013, USCS employed 2,100 people.³⁸

Asda CO₂/Ammonia Cascade Distribution Centers (UK)

UK retailer Asda transitioned its 45,801 m² (493,000 ft²) Rochdale central distribution center in 2012 to a CO₂/ammonia cascade system.³⁹ The two-stage pumped circulation cooling system from Star Refrigeration provides 1 MW of cooling for the frozen cold store, 1.7 MW for a new chill chamber and 0.5 MW for the produce chamber.⁴⁰ Among the features offered, the refrigeration plant has an energy saving system, which reduces the speed of the condenser fan and provides floating head pressure control in order to increase system performance.⁴¹ Star Refrigeration has previously fitted Asda with CO₂/ammonia cascade systems at a number of other UK locations, including a central distribution center near Leicester.⁴²

About Asda: Asda is headquartered in the UK with 525 stores across the UK. The company has been



Star Refrigeration Cascade System at Asda Distribution Center³⁸

wholly-owned by Wal-Mart since 1999 and employs 160,000 people.⁴³

About Star Refrigeration: Established in 1970, Star Refrigeration is one of the largest independent industrial refrigeration engineering company in the UK. Star Refrigeration specializes in providing cooling solutions to enable end users to reduce their environmental impact, while reducing lifecycle operating costs. As of 2014, Star Refrigeration launched a U.S. based company, Azane, Inc., which is set to market low-charge ammonia freezers and chillers for the North American market.⁴⁴ The U.S. systems will be manufactured in Pennsylvania, U.S.⁴⁵

Brasil Foods Ammonia Refrigerated Plant (Brazil)

The Rio Verde Plant of Brasil Foods uses an ammonia system to cool and freeze its products.⁴⁷ The facility was developed in 1996 by Falkenstein and is a large meat processing production facility with floor space of 30,472 m² (328,000 ft²) and processing capacity of 280,000 chickens and 3,500 pigs per day.^{48,49} The refrigerated facility features freezing tunnels, cold storage, and chilled water/AC, but only needs a fifth of a standard refrigerant charge.⁵⁰ Over 80 percent of the industrial refrigeration market in Brazil use ammonia systems.⁵¹

Brasil Foods S.A.: Brasil Foods is the world's tenth largest food company with 50 factories throughout

Brazil, 33 distribution centers and service in more than 120 countries.⁵² In 2012, it had 110,000 employees.⁵³

About Falkenstein: Headquartered in Aulendorf, Germany and Blumenau, Brazil, Falkenstein specializes in architecture and engineering, and general planning services for complex building projects.⁵⁴ Falkenstein has around 50 employees and has been involved in more than 250 refrigeration installation projects worldwide.⁵⁵

Del Monte Indirect Ammonia Refrigeration Cold Storage Facility (U.A.E.)

Del Monte's ammonia refrigeration facility in Dubai, United Arab Emirates was built in 2007 and covers nearly 30,000 m² (322,920 ft²) with several cooling production lines, a cold storage room and a cooling chamber.⁵⁶ The indirect system is charged with 4,000 kg of ammonia that condenses at 40°C (104° F) and uses water for high-temperature rooms and glycol for lower temperature areas as secondary refrigerants.⁵⁷ Four plate heat exchangers provide the cooling capacity and the system's six high- and low-temperature 600 kW single-stage GEA Grasso screw compressors deliver the high-pressure vapor needed for an efficient system.⁵⁸ Capacity of the high-temperature level is 1,890 kW and the low side capacity runs at 1,800 kW, which provides cooling for about 4,082 tonnes of fruits and vegetables each year.⁵⁹



Brasil Foods Rio Verde Plant⁴⁶



GEA Open Screw Compressor MC Series
Image courtesy of Shecco

Fresh Del Monte Produce: Fresh Del Monte Produce was founded in 1886 and is a worldwide food and beverage company headquartered in George Town, Cayman Islands with offices and operations worldwide.⁶⁰ The company has a total of 44,000 employees as of 2013.⁶¹

GEA Grasso: GEA Grasso, part of GEW Group, was founded 150 years ago as a refrigeration compressor manufacturer and is based in the Netherlands and Germany.⁶² The German division manufactures screw compressors, packages, and liquid chillers, and is located in Berlin and Halle; while the Dutch division develops reciprocating compressors, packages and components, and is located in s-Hertogenbosch.⁶³ Grasso provides refrigeration and air-conditioning components for industrial scale food processing, air-conditioning, leisure (ice rinks and skiing), and industrial processes worldwide.⁶⁴ As of June 2012, GEA Group had 24,000 employees.⁶⁵

Beak & Johnston Ammonia Cold Storage (Australia)

Beak & Johnston's low and high temperature cold storage complex in Greenacre, Australia installed a two stage ammonia system in 2007.⁶⁷ The system includes three Mycom refrigerating compressors, and a Baltimore Aircoil evaporative condenser and HP receiver.⁶⁸ Australia has an estimated 13.05 million m³ (459 million ft³) of cold storage space and approximately 12.4 million m³ (438 million ft³) (95 percent) relies on ammonia refrigeration for cooling.⁶⁹ A study commissioned by the Australian government found ammonia systems to have 15 percent lower specific energy consumption in comparison to synthetic refrigerant systems.⁷⁰

About Beak & Johnston: Beak & Johnston is a local and family owned food processing business with plants located in New South Wales and Queensland, Australia.⁷¹ Customers include major retail chains and food service clients in Australia, as well as overseas.⁷² In 2012, Beak & Johnston had revenue of U.S. \$81.5 million.⁷³

About Mycom (Mayekawa): Established in 1924, Mayekawa is a manufacturing company that focuses on freezing and compression technologies and has



Beak & Johnston Cold Storage Complex ⁶⁶

a global reach with offices worldwide.⁷⁴ Mayekawa develops refrigeration systems with significant energy-savings and employs non-freon and CO₂ reduction technologies.⁷⁵

About Baltimore Aircoil: Baltimore Aircoil Company (BAC) is a worldwide manufacturer and marketer of evaporative heat transfer and thermal energy management equipment.⁷⁶ At its headquarters in Maryland, U.S., it has a research and development laboratory complex for evaporative heat transfer and thermal energy management equipment.⁷⁷ BAC has manufacturing facilities worldwide, including locations in Korea, China, Malaysia, India, and South Africa.⁷⁸ BAC reported revenue of U.S. \$37.5 million in 2013.⁷⁹

Unique Dairy Products Ammonia Refrigeration System (South Africa)

Unique Dairy Products, which has been supplying McDonalds' outlets in South Africa with ice cream, milk shakes and other milk products for over ten years, uses ammonia to cool its facility.⁸⁰ The facility is located in Pretoria, South Africa and has recently been updated in order to achieve the temperature control needed for a milk processing facility.⁸¹ The ammonia system replaced old synthetic gas equipment on the floor,



GEA Ammonia Heat Pump

Image courtesy of Shecco

in addition to replacing nine in-line synthetic gas freezers with three new ammonia freezers.⁸²

About Unique Dairy Products: Unique Dairy Products headquartered in Hermanstad, Pretoria, South Africa is a private company that manufactures ice cream and other dairy products.⁸³ The company was incorporated in 2002.⁸⁴

Star Refrigeration Ammonia System for Robert Wiseman Dairies (UK)

In 2008, UK-based company Star Refrigeration developed an ammonia/glycol system for Müller Wiseman's U.S. \$135 million Bridgewater facility in Somerset, England. The facility has been designed to produce 500 million liters (132 million gallons) of milk per year and has a total cooling capacity of over 3 MW. The system operates using ammonia as



Robert Wiseman Dairy⁸⁵

a primary fluid, in turn cooling glycol, the secondary fluid.⁸⁶ Furthermore, the energy efficient design also features economized screw compressors, inverter driven motors, floating head pressure control and heat recovery for warm glycol cooler defrosting that helps to reduce system costs.⁸⁷ Star Refrigeration reported in 2008 that the development saves Müller Wiseman Dairies approximately U.S. \$135,000 on annual running costs, when compared to fluorinated gas systems.⁸⁸ In addition to the ammonia refrigeration system, Star's Envitherm transcritical CO₂ heat

pump provides high grade heat recovery for office and water cooling.⁸⁹

About Müller Wiseman Dairies: Müller Wiseman dairies provide 30 percent of the milk consumed in Britain daily.⁹⁰ The company is headquartered in East Kilbride, Scotland and has a network of dairies and depots across the UK. From February to December 2013, the company reported revenues of around U.S. \$1.48 billion.⁹¹

About Star Refrigeration: See previous section on ASDA distribution plants.

Dalian Zhangzidao Fishery Group CO₂/Ammonia Cascade Cold Storage Facilities (China)

ZHANGZI ISLAND

The largest cascade CO₂/ammonia cold storage facility in northeast China is located on Zhangzi Island near Dalian and was opened in June 2013.⁹² The project is recognized as one of the key demonstration projects for HFC-free technology by the Chinese Ministry of Environmental Protection, as it is the first of its kind to install both cascade CO₂/ammonia and brine systems and has resulted in a 90 percent reduction of ammonia charge size.⁹³ According to the designer and contractor of the project, Yantai Moon Group, Dalian Zhangzidao Fishery Group has expressed complete satisfaction and is using a CO₂ refrigeration system for the new low-temperature cold storage facility the company



Yantai Moon
EIA

is currently constructing.⁹⁴ Danfoss provided the CO₂ solutions and components throughout the system, such as its AKS 4100U series radar liquid level sensor and the ICM series motor control valve, while in the freezing room Danfoss ICF series valve station is used leading to a reduction of installation area by two-thirds and welding processes by 80 percent.⁹⁵ Danfoss SVL series refrigeration components are also used in the system.⁹⁶

PORT OF DALIAN

In August 2012, Dalian Zhangzidao Fishery Group began construction of a 50,000 ton cold storage facility.⁹⁷ The facility is located at the Port of Dalian and is a six-story building with 12 freezing rooms with temperatures ranging from -25°C to -20°C, and an ultralow temperature cold room at -60°C.⁹⁸ Compared to a conventional ammonia system that uses 27,200 tonnes, the facility only needs three tons of ammonia leading to a 90 percent reduction of ammonia refrigerant charge.⁹⁹ Overall the facility achieves 30 percent annual energy savings and in the summer energy savings rise to over 50 percent.¹⁰⁰

About Dalian Zhangzidao Fishery Group:

Dalian Zhangzidao Fishery Group Co., Ltd is primarily engaged in breeding, raising, processing and distributing seafood products.¹⁰¹ Its products are distributed domestically in China, as well as internationally.¹⁰² Dalian Zhangzidao Fishery Group has a net income of U.S. \$79 million and 4,335 employees.¹⁰³

About Yantai Moon Group: Yantai Moon Co., Ltd. is a company within the Moon Group, which was founded in 1956 and is an enterprise for the national "Demonstration Project of Technology Progress in Machinery Industry and Enterprise," as well as being part of the "State-recognized Enterprise Technical Center."¹⁰⁴ Yantai Moon works on research and development, as well as large scale industry engagement ranging from complete sets of industry refrigeration plants to central air-conditioning.¹⁰⁵ At the close of 2011, Yantai Moon Co., Ltd. had total assets of over U.S. \$650 million and employed over 5,000 employees.¹⁰⁶

About Danfoss: Danfoss, headquartered in Denmark, is a global company with 56 factories in



Port of Dalian Cold Storage Facility

Image courtesy of Shecco

18 countries, 23,000 employees globally, and sales and distribution in 51 countries.¹⁰⁷ Danfoss' Climate & Energy division specializes in refrigeration and air-conditioning controls, power electronics, heating solutions, commercial compressors, and district energy.¹⁰⁸ The company manufactures pack controllers and front ends, evaporator controllers, CO₂ controllers, electronic regulating valves, line components and filters, sensors, pressure switches, and solenoid valves for commercial CO₂ applications.¹⁰⁹ See the commercial refrigeration section for further information about Danfoss.

Carnot Transcritical CO₂ Sports Center Cooling/Heating System (Canada)

In Montreal, Canada, Carnot Refrigeration installed a transcritical CO₂ system at the Dollars-des-Ormeaux ice rink complex to replace an old HCFC-22 system.¹¹⁰ The CO₂ system has many benefits and maximizes efficiency at the complex. The system cools three ice rinks and also provides the heating for two adjacent pools, a library, and a gym.¹¹¹ The system delivered 38 percent energy savings as a result of the transition from an old system using HCFC-22 in addition to the energy savings from heating of the pools, the library, and the gym.¹¹² The system includes 18 compressors, three brine pumps, one heating pump, four heat exchangers,



Carnot Transcritical CO₂ System
Image courtesy of Shecco

eight heat recovery units, two gas coolers, and about 2,474 kg of CO₂.¹¹³ Other benefits of the system include 60 percent less space needed for refrigeration equipment, 10 percent reduction in maintenance costs compared to a conventional system, and no cooling tower required.¹¹⁴ The system recently won an Energia Award in the Existing Building – Institutional Sector category from the Quebec Association of Energy Efficiency.¹¹⁵

Results from a simulation by the KTH School of Industrial Engineering and Management in Stockholm, Sweden suggest CO₂ systems are highly efficient for use in ice rink installations.¹¹⁶ The simulation showed 30 percent lower energy consumption than ammonia/brine systems and 46 percent lower than CO₂/brine systems, along with having a high COP of 6.4.¹¹⁷ These improvements also make the life cycle cost of the CO₂ 13 percent lower than traditional ammonia/brine systems.¹¹⁸

About Carnot: Since 2008, Carnot Refrigeration of Trois-Rivieres, Quebec has developed commercial and industrial systems that reduce the environmental impact of refrigeration.¹¹⁹ Carnot Refrigeration systems focus on the designs that use environmentally-friendly natural refrigerants, such as CO₂ and cascade ammonia/CO₂ systems and the company is working to make eco-friendly refrigeration a global standard. The company has been involved in numerous applications of transcritical CO₂ systems throughout Canada and the U.S.¹²⁰

GEA Refrigeration Technology Ammonia Refrigeration Plant (Russia)

Russia has unveiled its first ammonia-based refrigeration plant for use in a sports facility. The project is a joint venture of GEA Refrigeration Technologies and NPO Mostovik, one of the largest construction companies in Russia.¹²¹ The plant, which contains four screw-compressor units, offers a cooling capacity of 4.2 MW.¹²² Located in Krasnaya Polyana the plant was used to cool the 1,814m bobsleigh track that was used in the Sochi Winter Olympics. The track is served by 4 km of main ammonia piping with positive evaporation enthalpy and volumetric cold duty reported.¹²³ The use of



GEA Grasso Screw Package
Image courtesy of Shecco

ammonia means the system not only requires a lower-volume of refrigeration, but also requires a lower diameter of piping, helping to reduce costs. While numerous quality inspections and pressure tests have been conducted to ensure optimum safety standards, a GEA-installed gas scrubber helps to further minimize health risk by filtering any escaping ammonia out of the air in the event leakage occurs.¹²⁴ Ammonia based-refrigeration systems have become popular in many places in Europe, being used in approximately 85 percent of ice rinks in Sweden,¹²⁵ and adopted in a number of

ice rinks in the UK with reported reduced operating costs and improved energy efficiency.¹²⁶

About GEA Refrigeration Technologies:

GEA Refrigeration Technologies, is part of the GEA Group, operating around the world to provide solutions to the food and beverage sector and the petrochemical, pharmaceutical, fishing and leisure industries.¹²⁷ As of December 2013 GEA, generated revenues of more than U.S. \$5.9 billion and employed 18,000 people worldwide.¹²⁸

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TRANSPORT REFRIGERATION

Refrigerated vehicles, semi-trailers, lorries, intermodal containers, trains, ships and fishing vessels are essential to the successful transport of perishable goods and frozen products from production facilities to distribution centers to the sales floor.

The technical requirements of transport refrigeration systems are demanding, as the equipment has to operate over a wide range of ambient temperatures and weather conditions, in addition to withstanding frequent vibrations and shocks.¹ Furthermore, the systems need to be compact to maximize cargo space, as well as being lightweight and efficient to reduce the energy and fuel needs of the vehicle or vessel.

The refrigerant charge size of transport refrigeration equipment depends on the refrigeration capacity of the system as well as its specific application. On average, synthetic refrigerant charge sizes range from 4.5 to 7.5 kg for road vehicles, railcars, and intermodal containers, and 100 to 500 kg for conventional synthetic equipment aboard ships.² Transport refrigeration equipment operate over temperature ranges similar to commercial refrigeration equipment with medium and low temperature ranged systems.³ Hydrofluorocarbon (HFCs) gases commonly used in transport refrigeration are: HFC-404a and HFC-410a, which are used for long-distance vehicles carrying chilled and deep frozen products; and HFC-134a, which is used for transporting chilled products.⁴ Low-GWP alternatives are being tested, proven and commercialized for all types of transport refrigeration, making clear that these HFCs can now be replaced.

As demand for transportation of frozen and chilled goods grows worldwide, the use of HFC-free refrigeration has an increasingly important

role in helping companies meet company-wide greenhouse gas reduction goals and comply with fluorinated gas laws and regulations, such as the recently revised EU F-gas Regulations. HFC-free systems are being used commercially and new HFC-free systems are currently being developed, tested, and sold on the market. HFC-free transport refrigeration not only significantly reduces a company's greenhouse gas emissions, but it also has significant potential to save money through energy efficiency gains and lower refrigerant costs. HFC-free alternatives include CO₂, CO₂/ammonia cascade, hydrocarbons, and nitrogen systems. Currently, CO₂ is used to refrigerate transport systems in a number of countries. The advantages of CO₂ as the refrigerant are that it creates no breakdown products, has a high cooling capacity, is non-combustible, and is available at a low cost worldwide.⁵

Ammonia has a high refrigeration efficiency, zero ODP, and zero GWP which make it the refrigerant of choice in the fishery industry, particularly in developing countries.⁶ Cascade CO₂/ammonia systems are also currently being successfully used in many marine transport uses as described in the case studies below. A number of different types of hydrocarbons are being tested, proven and commercialized, the most popular of which are propane and isobutane.⁷ Hydrocarbons are non-ozone depleting and non-toxic, and are available at low-cost, with notable energy efficiency gains over conventional fluorinated gases.⁸ As in other applications, the flammability of hydrocarbons

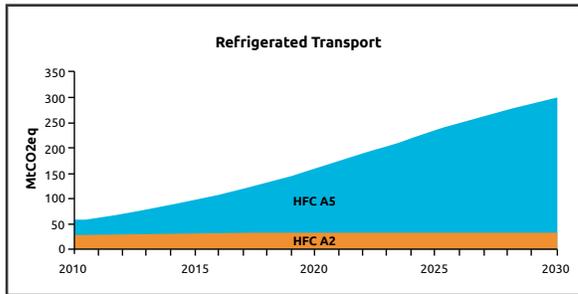


Figure 1: BAU Consumption of HFCs and HFCs from Transport Refrigeration (A2 = developed countries A5 = developing countries)¹²

is being effectively controlled to make their use safe in transport applications. Finally, nitrogen has a number of advantages over HFC refrigerants, including helping to lower noise generation of vehicles, dramatically reducing greenhouse gas refrigerant emissions, and reducing diesel emissions and particulate pollution.⁹

HFC consumption in transport refrigeration is expected to grow substantially in the coming years under a business as usual scenario (Figure 1).¹⁰ The rapid development and commercialization of modern and improved HFC-free systems could markedly change these predictions and substantially reduce related emissions of greenhouse gases.

Case studies of HFC-free applications in refrigerated transport are described below:

Carrier Transicold CO₂ Refrigeration System (Global)

In 2010, U.S. based company Carrier Transicold (United Technologies) developed the world's first naturally refrigerated container in conjunction with leading global liner shipping company, Hapag-Lloyd.¹² The NaturaLINE system incorporates CO₂ in place of HFC refrigerants HFC-134a and HFC-404A, which have GWPs of 1,320 and 3,922 respectively.¹³ In doing so, the units provide optimum energy efficiency while reducing combined direct and indirect emissions by 10 percent below that of the closest competitive model.¹⁴ The systems also significantly reduce electricity requirements, helping to generate lower shipping line fuel costs.¹⁵ Throughout its 2012 trial, the NaturaLINE units



Carrier Transicold NaturaLINE CO₂ System¹¹

withstood temperature ranges from -22°C (-7.6°F) to 13°C (55°F) on Atlantic and Pacific trade routes.¹⁶ Hapag-Lloyd is now using these CO₂ containers in real conditions around the world. The systems have been trialed on a wide range of products with positive results to date.¹⁷ While the traditional user interface has been maintained to facilitate ease of operation, the refrigerant management system includes a purpose-built, multi-stage compressor, in addition to a wrap-around cooler with optimized heat-transfer surfaces.¹⁸

About Carrier Transicold: Carrier Transicold (subsidiary of United Technologies Corporation (UTC)) is headquartered in the United States and is a global company in transport refrigeration systems.¹⁹ Carrier Transicold, part of UTC Climate, Controls & Security, has a complete line of equipment designed for refrigerated trucks, trailers and containers.²⁰ UTC had approximately 4,000 locations in 71 countries and 218,300 employees, with revenue of U.S. \$57.7 billion as of 2012.²¹

About Hapag Lloyd: Operating in more than 114 countries, Hapag-Lloyd transports more than five million TEU (Twenty-foot Equivalent Unit) annually.²² Hapag-Lloyd currently offers nearly 100 liner services which operate between all continents.²³ In the first six months of 2013, the company achieved revenues of U.S. \$5.5 billion.

Sainsbury's CO₂ Refrigerated Trailer (UK)

UK-based retailer Sainsbury's, announced in September 2013 that it is trialing one of the world's first 100 percent natural refrigeration trailers in collaboration with Carrier Transicold (United Technologies).²⁴ As noted above, Carrier's NaturaLine refrigeration system was first developed for deep-sea containers, Carrier has since begun applying this technology to other transport applications. This is the first time Carrier's NaturaLine system has been mounted to a trailer. If the current demonstration project proves successful Sainsbury's has announced that it will convert its fleet, which would help the company reduce 70,000 tonnes of CO₂ equivalent emissions annually compared to its current fleet.²⁵ NaturaLine trailers will aid in Sainsbury's efforts to reduce depot-to-store transport emissions of CO₂ by 35 percent in 2020 and an absolute reduction of 50 percent of its transport emissions by 2030.²⁶



Sainsbury's CO₂ Refrigerated Trailer

Reproduced by kind permission of Sainsbury's Supermarkets Ltd

About Sainsbury's: Sainsbury's was founded in 1869 in the United Kingdom and now operates 1,016 grocery and convenience stores.²⁷ One of the largest grocers in the UK²⁸, Sainsbury's had a total revenue of about U.S. \$36.2 billion in 2012, and the company employs 152,000 people.²⁹ To date Sainsbury's has over 160 HFC-free stores.³⁰ As part of its sustainability plan, Sainsbury's has set a target to have 250 stores of all sizes on HFC-free systems by the end of 2014, including both new and refurbished stores.³¹

Johnson Controls Cascade Ammonia/CO₂ Fishing Vessels (Global)



Fishing Vessel using Johnson Controls Cascade System²⁸

Johnson Controls Marine cascade CO₂/ammonia technology uses CO₂ on the low-temperature side and ammonia on the high-temperature side.³² The systems energy efficient compressors in combination with frequency converter drives help maintain high freezing capacity, improved COP³³ compared to other refrigerants, and the use of CO₂ reduces equipment size and greenhouse gas refrigerant emissions.³⁴ Johnson Controls reports that the system preserves perishable foods, while running at the low operation costs due to energy efficiency improvements.³⁵

About Johnson Controls: Johnson Controls, headquartered in the U.S., serves customers in more than 150 countries.³⁶ Johnson Controls has 170,000 employees and in 2013 had revenue of U.S. \$42.7 billion.³⁷

DSI CO₂ Plate Freezers (Global)

Danish company, Dybvad Stal Industri (DSI) designs and manufactures vertical and horizontal plate freezers for the transportation and processing of seafood. The freezers are suitable for both onshore and marine installations. DSI claims that the advantages of CO₂ are substantial, with CO₂ freezers reducing freezing times by 25 to 50 percent, helping to better preserve the natural quality of frozen products.³⁸ This fast-acting process reduces energy consumption and lowers initial energy costs.³⁹



DSI CO₂ Plate Freezer⁴⁰

Namibian company MEATCO⁴¹ and the Arkhangelsk Trawler Fleet in Russia are two of the users which have purchased the freezer plates and are using them in their operations.⁴²

About DSI: Founded in 1969, DSI is a leading company involved in designing and manufacturing manually-operated and automatic plate freezers. With approximately 40 employees, DSI optimizes the operating performance, reliability and overall economy of its freezers on an ongoing basis to ensure that they provide its customers with the best possible new technological possibilities.⁴³

Thermo King's Cryotech Refrigeration System (Europe, U.S.)

Thermo King developed a refrigeration unit using liquid CO₂ as the refrigerant in an open-loop system.⁴⁴ The CO₂ used for refrigeration is



Thermo King Cryotech Refrigerated Truck⁴⁴

a by-product of ammonia production, therefore further limiting greenhouse gas emissions.⁴⁵ The unit was developed in the Republic of Ireland and has been deployed in Finland, Denmark, France, Germany, Norway, Poland, the Netherlands, Sweden, and the U.S.⁴⁶ Thermo King's Cryotech system has over 500 successful applications of HFC-free transport refrigeration. The system is able to reduce total greenhouse gas emissions of transport refrigeration units by 75 to 90 percent.⁴⁷ The system also achieves improved performance, is substantially quieter, and offers faster temperature recovery when compared to conventional units.⁴⁸ Retailer Spar Netherlands has converted 100 percent of its fleet to these systems,⁴⁹ reducing its transport carbon footprint by 27 percent.⁵⁰

About Thermo King: Thermo King (subsidiary of Ingersoll Rand) is based in the U.S. and is a manufacturer of transport temperature control systems, as well as HVAC systems for transportation.⁵¹ Ingersoll Rand has a total 52,000 employees and reported 2011 profits of U.S. \$317.4 million.⁵²

AGA Cryogenic Refrigerated Trailers (Europe)

AGA manufactures transportation coolers that use cryogenic agents, such as liquid nitrogen or liquid CO₂ to refrigerate perishable goods. Among the benefits of using these alternatives, AGA states that the systems allow for low noise operations, low maintenance, low investment and exact fixing of temperature points.⁵³ The use of liquid CO₂ as a cooling agent for dry ice means that temperatures can be kept low for several days during transportation. AGA claims that it is easier to increase the capacity of a natural gas-system during times of peak load than for conventional HFC systems, as there is no need for an aggregate.⁵⁴ These systems use reclaimed CO₂ captured from industrial processes that would otherwise be released into the atmosphere.⁵⁵

About AGA: Operating in Scandinavia and the Baltic region, AGA is an industrial gas company in northern Europe, and forms part of the Linde Group, a supplier of gases and engineering works,



with services spanning more than 100 countries.⁵⁶ In the 2012 financial year, the Linde Group generated U.S. \$21.18 billion in revenue.⁵⁷

natureFridge Liquid Nitrogen Refrigeration System (Global)

natureFridge has developed liquid nitrogen refrigeration systems for all sizes of refrigerated trucks and trailers, including one-compartment, dual compartment, and longitudinal-compartment trucks, and one-compartment, dual-compartment, three-compartment, longitudinal-compartment, and double-decker trailers.⁵⁸ natureFridge uses nitrogen as its refrigerant and liquefies it bringing it down to a temperature of -196°C (321°F), before spraying the nitrogen throughout the inside of the trailer leading to even distribution of cooling.⁵⁹

One trailer can reportedly save around 30 to 38 tonnes of CO₂e tonnes, which for a fleet of 200 refrigerated trailers a business could see overall greenhouse reductions of about 6,804 tonnes.⁶⁰ Due to the system having few moving parts and no compressor, the design also reduces noise generation, allowing for quiet nighttime deliveries.⁶¹ natureFridge’s use of liquid nitrogen has helped significantly reduce the costs of running the system compared to a traditional diesel-powered refrigeration unit.⁶² The running costs of a unit are proportional to the consumption of nitrogen, which ranges from 20 to 40 liters per hour depending on outside

temperature and with nitrogen at a price of around \$0.13 per liter the system can save over U.S. \$2,500 per trailer per year on fuel costs.⁶³ In 2010, the Shoprite Group, became the first South African company to use nitrogen-powered refrigeration in its transportation, reporting that the new systems maintain better moisture retention helping to reduce product wastage.⁶⁴

About natureFridge: natureFridge, also known as ecoFridge Production Company Ltd., is a global company based in Ukraine with business partners and suppliers in the U.S., UK, China, Taiwan, France, and South Africa.⁶⁵ Woolworths South Africa, Safeway, Carrefour France and Asda UK are among the retailers that have trialed or purchased ecoFridge transportation systems.⁶⁶

Lidl Eutectic Plates (UK)

Lidl UK uses eutectic plates to freeze perishable goods at distribution centers before transporting them to stores. Cooled to -24°C, the brine-filled plates may then be placed within insulated transportation containers to preserve goods, without the use of additional refrigerants to cool the trailer.⁶⁷ In doing so, vehicles may be used to transport frozen items, but avoid the greenhouse gas refrigerant emissions from conventional HFC-404a transportation systems. As of 2011, there were approximately 8,500 of these insulated containers in operation in the UK at a total investment of about U.S. \$14.32 million.⁶⁸



Lidl Refrigerated Truck

Image courtesy of Bonsai Truck.

Introduced in 2001, Lidl estimates around 14,000 tonnes of CO₂ equivalent (tCO₂e) have been saved during the first 10 years of their use.⁶⁹ In Germany, where Lidl is headquartered, CO₂ and ammonia refrigeration systems are used in a number of logistic centers in Kerpen, Paderborn, Berlin and Hamburg to help further reduce the overall emissions associated with the transportation of goods.⁷⁰

About Lidl UK: Lidl has more than 13,000 employees in over 590 stores across the UK.⁷¹ In 2013, the British subsidiary of the Lidl & Schwarz group achieved a reported turnover of over U.S. \$5.558 billion.⁷²

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COMMERCIAL REFRIGERATION

Commercial refrigeration encompasses a variety of applications including supermarkets, convenience stores, restaurants, and other food service establishments.¹

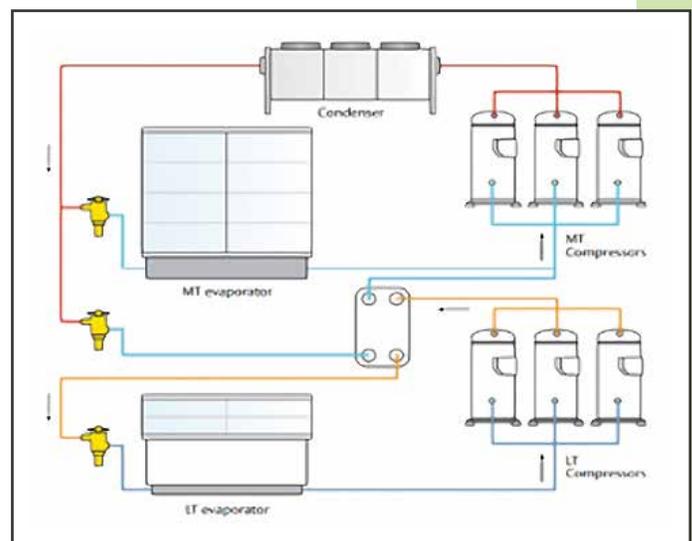
By 2015, commercial refrigeration equipment is expected to account for 47 percent of the total annual refrigerant emissions making this type of equipment the largest source of CO₂ equivalent emissions of chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) refrigerant gases.² Commercial refrigeration systems are comprised primarily of two levels of temperature: medium temperature (1°C/34°F to 14°C/57°F), which is used for chilling food (e.g., vegetables, milk, eggs) with refrigeration equipment evaporating temperatures varying between -15°C/5°F and 1°C/34°F; and low temperature (-12°C/54°F to -20°C/-4°F), which is used for freezing food with evaporating temperatures ranging from -35°C/-31°F to -40°C/-40°F.³ The lifetime of commercial refrigeration equipment typically ranges from 15 to 20 years,⁴ and is categorized into three types of systems:

Centralized Rack Systems

Centralized Rack Systems are the most common systems used in supermarkets and are built with multiple compressors mounted to a rack in a machinery room with a roof top condenser and piping that connects the system to the store's display cases.⁵ Charge sizes vary from 270 to 2,990 kg according to size of the supermarket, design of the store, and the type of refrigeration technology installed.⁶ Advanced HFC-free centralized systems in use are:

Ammonia or Propane Cascade Systems

Cascade systems are designed with two compressor rack systems, a medium temperature side and a low temperature side with the two systems linked by a common heat exchanger.⁷ Cascade



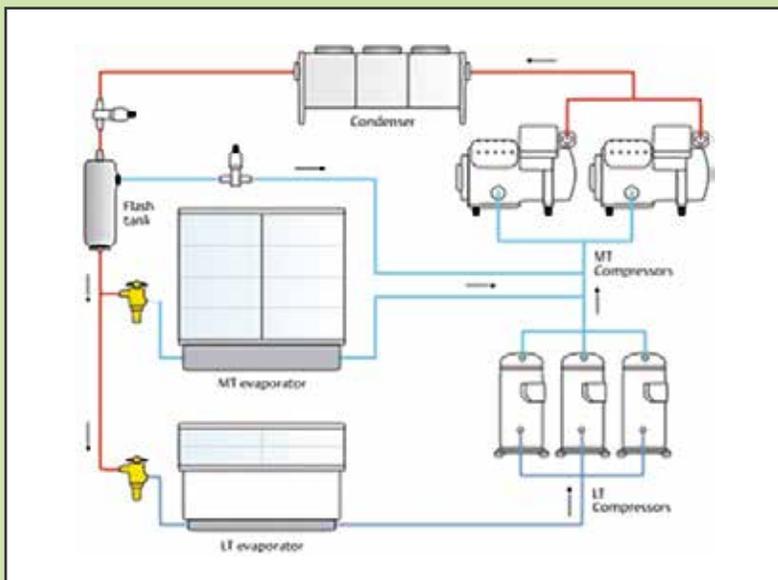
Cascade System Schematic

Image courtesy of Emerson Climate Technologies

systems are designed to maintain CO₂ pressures and temperatures below the critical point, which is the highest pressure and temperature where the refrigerant can still condense.⁸ In a typical HFC-free system, ammonia or propane (HC-290) is used as the primary refrigerant to chill the secondary refrigerant (CO₂), which is pumped throughout the stores refrigerated display cases increasing safety of the system for consumers by restricting the ammonia or hydrocarbons to unoccupied spaces and only circulating CO₂ in occupied areas of the store.⁹

Transcritical CO₂ Systems

Transcritical CO₂ systems use CO₂ as the only refrigerant. A transcritical system operates above and below the critical point (described above), as



CO₂ Transcritical System

Image courtesy of Emerson Climate Technologies

compressors release CO₂ gas above the critical pressure to the condenser, which then reduces the temperature of the gas without liquefying; the cooled gas then passes through a pressure reduction valve where a portion of the gas liquefies, and is then separated from the gas in a flash tank and distributed throughout the store cabinets through piping.¹⁰ The excess flash gas is then sent to the suction of the medium temperature compressor, but if the system is installed in a warm region an additional flash gas compressor can be installed to raise system efficiency.¹¹ Transcritical CO₂ systems have shown to have 10 to 35 percent better energy efficiency than synthetic refrigerant based systems in supermarket applications.¹² As of November 2013, the EU had 2,881 transcritical CO₂ installations¹³, by February 2014 Canada had at least 65 transcritical CO₂ stores¹⁴, by 2015 Japan is predicted to have approximately 600 transcritical CO₂ systems, and currently South Africa has a total of 17 transcritical CO₂ systems.¹⁵ Transcritical CO₂ systems were approved for use in the U.S. in 2012 after Hillphoenix's Advansor system received certification from the safety consulting organization, Underwriters Laboratory.¹⁶ As of April 2014, the U.S. had four transcritical CO₂ systems installed.

Condensing Units

Condensing units are used in small scale commercial refrigeration using only one or two compressors, a condenser, and a receiver that are linked to a few display cases in the store through piping with synthetic charge sizes varying from 0.5 to 20 kg.¹⁷ HFC-free condensing systems include propane/hydrocarbon blend units and transcritical CO₂ systems.¹⁸ Condensing units are essentially small-scale versions of centralized systems.

Stand-alone Units

Stand-alone units include freezers, vending machines, and beverage coolers that are entirely factory assembled. HFC-free stand-alone units are currently used worldwide; stand-alone units using hydrocarbon or CO₂ as refrigerants are being rapidly adopted. Direct hydrocarbon systems using propane or isobutane have charges of less than 150 grams with energy efficiency improvements of 5 to 15 percent compared to HFC units.¹⁹ A method that combines the use of stand-alone hydrocarbon systems with water-cooling has enabled refrigerant charges to be dramatically reduced. This technology uses factory made stand-alone units, but has them connected by pipes with cold water circulating among the units

A method that combines the use of stand-alone hydrocarbon systems with water-cooling has enabled refrigerant charges to be dramatically reduced.

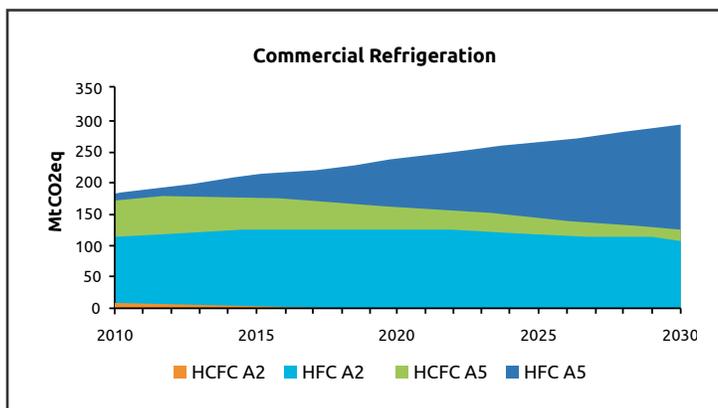


Figure 3: Global BAU Consumption of HCFCs and HFCs from Commercial Refrigeration³

(A2 = Developed Countries A5 = Developing Countries)

to remove excess heat. The cold water is often chilled with a hydrocarbon chiller on the roof of the retail unit to further reduce energy consumption and the refrigerant charge. CO₂ stand-alone systems have been installed all over the world and are showing energy efficiency improvements of between 18 to 37 percent compared to HFC-134a units depending on the climate, with some advanced micro-distributed systems achieving as much as 79 percent increased efficiency.²⁰

HFC-free technologies are available now and are shown to have significant advantages over HFC systems, both preventing emissions of super greenhouse gases and mitigating indirect emissions through improved energy efficiency. HFC-free systems in retail applications have already been tested and installed throughout the world in all climatic zones. Figure 3 shows projected Business As Usual trends of HFC consumption in developed (A2) and developing (A5) countries for commercial refrigeration. HFC consumption in developed countries is already at objectionably high levels, while consumption in developing countries is increasing at 10 to 15 percent per year and set to outpace HFC use in developed countries within the next decade. This growth in HFC use will have dramatic impacts on the climate, but technology is available to reduce current use and prevent the predicted growth in HFC use in developing countries. There are both economic and environmental reasons for a rapid transition to commercial refrigeration systems with

low-GWP refrigerants. For example, transitioning to a CO₂ system can reduce the carbon footprint of a supermarket by over 60 percent²¹, along with greatly increasing overall system energy efficiency (10 to 35 percent)²² and reducing overall operating costs.

Case studies of some of these HFC-free technologies for commercial refrigeration are described below:

Woolworths Transcritical CO₂ Refrigeration Systems (South Africa)

In 2010, Woolworths installed a transcritical CO₂ system with a capacity of approximately 300 kW in its store in Cape Town, South Africa.²⁴ The store has achieved energy efficiency improvements of 45 percent and, as a result, Woolworths has decided to make transcritical CO₂ systems a standard in all of its stores. As of May 2014, Woolworths has already installed 24 systems using CO₂ as its refrigerant.²⁵ The Cape Town store features controls, electronic expansion valves, pack controllers, heat exchangers and plate heat exchangers by Danfoss, resulting in significantly reduced energy use.²⁶ The store also has several other improvements including: LED lighting that adjusts to the amount of available natural light, floor heating that uses recycled waste heat from the refrigeration systems, and an experimental truck refrigeration system that uses liquid nitrogen as the refrigerant.²⁷



Woolworths Store in South Africa²³

About Woolworths Proprietary Limited:

Founded in 1931 in Cape Town, South Africa, Woolworths is a food, clothing and general merchandise retailer with 365 food locations

throughout South Africa, Botswana, Namibia, Zambia, Mozambique, and Ghana.²⁸ Woolworths' parent company is Woolworths Holdings Limited.²⁹

About Danfoss: Danfoss, headquartered in Denmark, is a global company with 56 factories in 18 countries, 23,000 employees globally, and sales and distribution in 51 countries.³⁰ Danfoss' Climate & Energy division specializes in refrigeration and air-conditioning controls, power electronics, heating solutions, commercial compressors, and district energy.³¹ The company manufactures pack controllers and front ends, evaporator controllers, CO₂ controllers, electronic regulating valves, line components and filters, sensors, pressure switches, and solenoid valves for commercial CO₂ applications. The EKC 326 Controller for gas cooling is used in transcritical CO₂ and cascade retail applications and helps systems achieve optimal coefficient of performance (COP).³² In 2002, Danfoss became a signatory to the ten principles of the UN Global Compact Initiative and has instituted an energy savings project focusing on improving the climate and energy footprint of its products and decreasing the consumption of energy of its 15 largest factories.³³

Lawson's Transcritical CO₂ Refrigeration System (Japan, Indonesia)

In 2013, Lawson installed a transcritical CO₂ system in the sub-tropical climate of Okinawa, Japan's southernmost island. The system is showing energy efficiency improvements of up to 21 percent compared to a conventional HFC-404a system even in this warm climate.³⁵ The system by Sanyo (Panasonic) uses split cycle technology to achieve the energy efficiency improvements, which lowers the pressure of CO₂ to an intermediate pressure level increasing the cooling effect of the system.³⁶ Lawson has 157 transcritical CO₂ stores in Japan alone, with additional transcritical CO₂ stores throughout Asia.³⁷ Lawson recently opened a CO₂ transcritical store in Jakarta, Indonesia with energy efficiency improvements of up to 39 percent.³⁸ In 2010, a Sanyo Smart Energy System was installed in a Lawson convenience store featuring photovoltaic modules and a lithium-ion battery system for power storage, along with a CO₂ refrigeration



Lawson Store in Shanghai³⁴

system, resulting in a highly energy efficient convenience store.³⁹

About Lawson: Lawson's, headquartered in Tokyo, first opened in 1975 in the Osaka Prefecture and has a total of 6,404 employees⁴⁰ with locations throughout Japan (11,609 stores) and China—Shanghai (292), Chongqing (77), Dalian (18), Beijing (5)—along with locations in Indonesia (63), Thailand (29), and Hawaii (4).⁴¹

About Panasonic/Sanyo: Panasonic is a global company that acquired Sanyo Electric in 2010 and manufactures a variety of products, including refrigeration and air-conditioning systems.⁴² Panasonic's Air-Conditioner Business Division is based in Gunma, Japan and features several CO₂ rotary 2-stage compression refrigeration systems for various sized commercial applications.⁴³



Panasonic CO₂ Systems
Image courtesy of Shecco

Panasonic's CO₂ systems have been widely adopted throughout Japan and Southeast Asia by retailers such as Lawson, Aeon, Seiyu, and others.⁴⁴ Panasonic produces products for large commercial applications, as well as small retail applications (convenience stores). The Panasonic CO₂ outdoor condensing unit shows energy efficiency improvements of 30 percent over HFC-404a systems.⁴⁵

New World Transcritical CO₂ Refrigeration System (New Zealand)



New World Supermarket⁴⁶

The 2,400 m² (25,830 ft²) store in Wellington, New Zealand is Foodstuffs' second transcritical CO₂ store and is showing 8 percent energy efficiency improvements over a hybrid CO₂/HFC-134a cascade system installed in another Foodstuffs store.⁴⁷ The system installed by Cowley Services features a rack system by Bitzer Australia that contains seven CO₂ compressors in a booster configuration with four 4FTC-30K and one 4FTC-15K compressors making up the medium-temperature side and two 2HHC and one 2HSL compressors making up the low-temperature side.⁴⁸ The low-temperature side has a refrigeration capacity of about 21 kW at -36°C (96.8°F) and the medium-temperature side has about 150kW capacity at -10°C (14°F) with CO₂ charge sizes less than 150kg.⁴⁹ The system controls are built by Emerson; and includes an Alfa Laval gas cooler and room evaporators with electronically commutated fans.⁵⁰ Overall, the store has reduced

its carbon emissions by 40 percent in comparison to supermarkets with conventional HFC systems.⁵¹

About New World (Foodstuffs): Founded in 1963, New World, headquartered in Wellington, is a 100 percent New Zealand owned and operated supermarket with 138 locations.⁵² New World is owned by Foodstuffs (NZ) Limited, which owns three retailers in New Zealand and has a total of 680 stores and wholesale outlets throughout the country.⁵³

About Bitzer: For over 75 years Bitzer has been manufacturing refrigerant compressors, condensing units and pressure vessels for refrigeration and air-conditioning systems with more than 30 subsidiaries operating worldwide in over 90 countries.⁵⁴ Bitzer's C4 Octagon semi-hermetic reciprocating compressor for transcritical CO₂ applications obtains high energy efficiency with a large volume suction gas cooled motor, efficient working valves, and cylinder heads with separate thermally isolated high- and low-pressure chambers.⁵⁵



Bitzer 4FTC-30K Transcritical CO₂ Compressor
Image courtesy of Shecco

About Emerson: Emerson Climate Technologies is a global provider of heating, ventilation, air-conditioning and refrigeration solutions for residential, commercial, and industrial applications.⁵⁶ Emerson has been part of over 25,000 supermarket installations around the world.⁵⁷ Emerson's E2 Facility Management System helps retailers reduce energy and maintenance



E2 Facility Management System

Image courtesy of Emerson Climate Technologies

costs by offering complete control of building and refrigeration systems including: compressor groups, condensers, walk-ins, HVAC units and lighting.⁵⁸

About Alfa Laval: Alfa Laval is a global provider of specialized products and engineering solutions to heat, cool, separate and transport products in the food and beverage industry with locations throughout

Europe, Asia, Australia, Africa, and the Americas.⁵⁹ Its products focus on heat transfer and separation, as well as fluid handling. Alfa Laval's Alfa-V CO₂ Air Gas Cooler replaces the traditional air cooled condensers in a conventional refrigeration system and has benefits of minimizing refrigerant charge due to smaller diameter copper tubes and the corrugated aluminum turbo fins, which also help obtain exceptional heat transfer.⁶⁰



Alfa-V CO₂ Air Gas Cooler

Image courtesy of Shecco

Carrefour Transcritical CO₂ Systems (Turkey, Romania)

In May 2012, Carrefour reopened a store in Istanbul, Turkey, retrofitted with a transcritical CO₂ system with project assistance from M&N Architecture. The switch from an HFC-404a



Carrefour Express Store⁶¹



Advansor Transcritical CO₂ System
EIA

refrigeration system to a transcritical CO₂ system reduced the store's greenhouse emissions by 3,400 times; it also improved the overall energy efficiency of the system by about 15 percent.⁶² The quality of the modern system has also delivered a decrease in refrigerant leakage by 75 percent due to improved pipe fittings.⁶³

Carel, a global company based in Italy was involved in Carrefour's first system using CO₂ in Turkey and several of its components are used in the Istanbul system,⁶⁴ including its pRack pr200T controller which manages the entire compressor rack (low temperature, medium temperature, and the transcritical section), the high pressure valve and the two regulating pressure receiver valves.⁶⁵ The store's 17 medium temperature showcases and two low temperature showcases are controlled by Carel's MPXPRO device in combination with E²V proportional expansion valves leading to improved evaporator efficiency.⁶⁶ Carel's Chillbooster technology increases efficiency by cooling the inlet air by 5 to 10°C through atomizing water into fine droplets that evaporate to cool the air, which allows the condensers to deliver their rated capacity even during the hottest periods of the year.⁶⁷ The entire system is managed by Carel's PlantVisor PRO supervisor system.⁶⁸

In November 2013, Carrefour also opened its first Romanian transcritical CO₂ hypermarket in Galati using an Advansor compSUPER system.⁶⁹ The system combines the use of CO₂ for both

low temperature and medium temperature with parallel compression technology in order to enhance energy performance in extreme high or low ambient temperatures.⁷⁰ As the production of flash gas can increase in CO₂ systems operating in warmer climates and increase the energy demands of the system, the parallel compressors are installed to address this problem.⁷¹ Instead of being removed at the low temperature and medium temperature stages, the majority of flash gas generated in a parallel compression system is removed at a higher pressure, resulting in a low energy penalty and high energy savings.⁷² The parallel compressors have already been tested in Denmark where they recorded energy savings of more than 20 percent above that of common (HFC) cascade systems.⁷³ The Advansor unit consists of 200 kW medium temperature and 45 kW low temperature capacities and has a CO₂ sensory alarm system to detect any leaks.⁷⁴

Carrefour has also been working with Carel to develop parallel compression systems with flash gas valves to operate at ambient temperatures of over 15°C (59°F).⁷⁵ As ambient air temperature increase, the system is said to become more efficient.⁷⁶ When testing the effectiveness of these systems, a booster with parallel compression used in Palermo, Italy (with an average temperature of 18°C/64°F) was found to have energy savings comparable to an HFC-134a/CO₂ cascade system.⁷⁷ Carrefour recently installed a parallel compression system in the warm climate of southern Spain near Valencia, which is showing energy efficiency improvements of 35 percent and a 90 percent reduction of CO₂ emissions compared to systems cooled by synthetic coolants.⁷⁸ Carrefour, in cooperation with Dorin Compressors and transcritical CO₂ system developer, Enex, has 10 transcritical CO₂ stores planned in Italy for 2014, in addition to other installations in warmer climates, such as southern France, Spain, and Romania.⁷⁹

About Carrefour: Carrefour, headquartered in Boulogne Billancourt, France, is the second largest retailer in the world with stores in 34 countries: 4,743 stores in France; 4,066 in the rest of Europe; 714 in Latin America; 373 in Asia, and 206 in other countries (Maghreb, Middle East, and Dominican Republic).⁸⁰ As of March 2014, Carrefour had

115 stores across Europe using CO₂ refrigeration technology including 23 CO₂ only stores.⁸¹ Refrigeration currently accounts for 35 percent of Carrefour's collective energy output. As this is its second largest controllable cost, Carrefour has a variety of actions to reduce its energy use including introducing bans on HFCs in new equipment from 2015, conducive to reducing its overall greenhouse gas emissions.⁸²

About Carel: Founded in 1973, Carel is headquartered in Brugine, Italy and is a global supplier of humidification and control systems in the HVAC&R market with a network of subsidiaries, affiliates, and sales organizations operating throughout 80 countries.⁸³



pRack pR300 Compressor Rack Controllers

Image courtesy of Carel

Carel's E²V Smart CO₂ & ammonia electronic expansion stepper valves offer a range of capacities to suit a small retail store using CO₂ condensing units and mini racks with pressures up to 140 bars; the valve can also be applied as the main high pressure and flash gas bypass valve in a transcritical CO₂ system.⁸⁴ They have developed an integrated system for refrigeration, air-conditioning and heat recovery. With its parallel compressor, this system has been found to be more efficient when outside temperatures are higher (above 15°C/59°F).⁸⁵



E3V Expansion Valve

Image courtesy of Carel

About Advansor (Hillphoenix): Denmark-based Advansor, owned by U.S. based Hillphoenix, develops and markets a range of HFC-free

heating and cooling systems that use CO₂ as their refrigerant. Advansor (Hillphoenix) operates in the UK, Switzerland, the Netherlands, Norway, Finland, Sweden, France, Turkey, Poland, Germany, Belgium, Luxembourg, Denmark, Mexico, Costa Rica, Canada and the U.S.^{86,87} Advansor's integrated parallel compression units are available in a variety of sizes making them suitable for full sized supermarkets as well as convenience and express store installations.⁸⁸ Hillphoenix Advansor transcritical CO₂ systems have been part of several installations of CO₂ systems in the United States and Canada, including Angelo Caputo's Fresh Market in Illinois, Whole Foods in Brooklyn, Roundy's Pick 'n Save Supermarket in Wisconsin, an Urban Fare store (Overwaita Food Group) in Vancouver B.C., and several Sobeys stores.⁸⁹

About Dorin Compressors: Based in Italy and founded in 1918, Dorin is a global company providing compressors for the refrigeration and air-conditioning industry.⁹⁰ Dorin developed its first transcritical CO₂ compressor in 1999 and today produces about 70,000 compressors a year.⁹¹

About Enex: Enex is a consulting and design company based in Italy specializing in environmentally-friendly air-conditioning, ventilation, refrigeration, and heat pumps using natural fluids and refrigerants.⁹²

Coop Sverige Integrated CO₂ Systems with Parallel Compressors (Sweden)

Advansor has also installed parallel compression and heat pump technology at a Coop Sverige store in Tocksfors, Sweden.⁹³ The system reclaims heat from the refrigeration process via two heat recovery units to transfer gas from the receiver to the high-pressure side, without the need of a gas bypass valve or false load evaporator.⁹⁴ Advansor reports this design has been able to heat both the building and local housing.⁹⁵ Operating at a capacity of 700kW, Advansor states the system is suitable for stores throughout Europe, including in the southern states with high ambient temperatures.⁹⁶

About Coop Sverige: Operating under the Swedish Cooperative Union (KF) Coop Sverige accounts

for 21.5 percent of the Swedish grocery sector.⁹⁷ In 2013, it had revenues of U.S. \$4.9 billion and employed 7,300 staff.⁹⁸ As of 2013, Coop Sverige had 25 stores equipped with CO₂ refrigeration systems and had committed to going HFC-free in all new stores.⁹⁹

About Advansor (Hillphoenix): See above case study.

Sainsbury's Transcritical CO₂ System in Small Retail Stores (UK)



Sainsbury's Local Convenience Store¹⁰⁰

In addition to its use of transcritical CO₂ in over 160 supermarket stores, Sainsbury's is also testing small transcritical CO₂ systems in convenience stores. In 2013, a new Sainsbury's convenience store in Haslucks Green outside of Birmingham, UK installed the company's first small transcritical CO₂ system, the Epta ECO₂-Small CO₂, which reduced greenhouse gas emissions from the store by 33 percent and increased the store's overall energy efficiency.¹⁰¹ Sainsbury's small scale transcritical CO₂ system is being looked at as a potential model for future applications in Sainsbury's convenience stores.¹⁰² The system has the benefit of reduced noise generation making it possible to install the system inside or outside.¹⁰³

About Sainsbury's: See transport refrigeration section.

About Epta Group: Epta is a European leader and global partner in the commercial refrigeration market with six brands: Costan, Bonnet Neve, George Barker, Eurocryor, Misa, and IARP.¹⁰⁴ Epta focuses on the design, production and installation of refrigerated display units, production units, and cold rooms. Epta specializes in customized product and refrigeration system solutions.¹⁰⁵

Aldi Süd Transcritical CO₂ Systems (Germany)

Discount-retailer Aldi Süd was the first German retailer to pioneer transcritical CO₂ refrigeration in 2006.¹⁰⁶ As of 2013, Aldi Süd had 151 stores using transcritical CO₂ stores, and since 2010, it has adopted transcritical CO₂ as its standard technology in all German stores.¹⁰⁷ Natural refrigerants marketing company, Shecco, a market development expert, estimates that from 2011 to 2013 the adoption of transcritical CO₂ systems in the German market increased by 158 percent, bringing the total number of stores running on these systems as of the end of 2013 to 429.¹⁰⁸

About Aldi Süd: Aldi Einkauf GmbH & Compagnie oHG is a German supermarket chain operating



Aldi Süd Store

Image courtesy of Stephen Mosel

through two separate groups, Aldi Süd and Aldi Nord.¹⁰⁹ Together, the groups have operations in Germany, the Republic of Ireland, the United Kingdom, Hungary, Austria, Slovenia, the United States and Australia.¹¹⁰ In southern Germany Aldi Süd operates over 1,816 stores.¹¹¹ Currently, over 10 percent of this retailer's display cabinets use CO₂ technology.¹¹² In addition, 79 percent of chest freezers use propane for low temperature refrigeration.¹¹³ The remaining 21 percent of Aldi Süd's chest freezers are expected to be replaced with natural-based systems by 2017.¹¹⁴ Aldi Nord, which operates 2,428 stores, use propane chest freezers in nearly half of its inventory, and 1 percent of its display cabinets use CO₂.¹¹⁵

Tesco CO₂ Systems (Europe, Asia)

Retail giant Tesco has expanded its climate-friendly refrigeration systems to China. As of June 2014, the company had 194 natural refrigerant systems in stores, a large number of which were located outside the UK.¹¹⁷ The supermarket in the city of Ningbo features a CO₂ cascade system manufactured by Carrier Corporation's Commercial Refrigeration division and is one of five HFC-free stores Tesco has opened in China, with similar systems installed in its stores in Beijing, Shanghai and Xiamen.¹¹⁸ The system is up to 24 percent more energy efficient than a traditional synthetic gas system.¹¹⁹ CO₂ has been perceived by Chinese industry as a viable alternative to conventional HFCs used in supermarkets as it has been documented to reduce refrigerant and energy costs.¹²⁰ Tesco China has underlined plans to adopt natural refrigerants in all of its stores.¹²¹

About Tesco: Tesco Plc started trading in 1924 and now has 3,146 stores in the UK, and has also expanded globally.¹²² As of 2014, Tesco employed 530,000 people throughout Europe and Asia.¹²³ In 2013, the company had U.S \$73.4 billion in revenues in the UK and a further U.S \$19.37 billion in Asia.¹²⁴

About Carrier Corporation (United Climate Technologies): Carrier Corporation is a manufacturer of commercial refrigeration systems and serves the beverage, food service, and food retail industries. Carrier Corporation is currently



Tesco Supermarket in Changping, China¹¹⁶

working on several innovations to increase efficiency of transcritical CO₂ systems in warm climates.¹²⁵ See Transport Refrigeration Section for additional information.

Migros Transcritical CO₂ and Transcritical CO₂ Systems with Parallel Compression Technology (Switzerland)

In 2009, Swiss retailer Migros partnered with Carrier Corporation to provide subcritical and transcritical CO₂ technology solutions to a number of Migros stores near Basel.¹²⁶ The systems were created to serve a capacity range of 25kW to 240kW per rack system.¹²⁷ Migros has been HFC-free in all of its 213 new installations since 2010.¹²⁸ CO₂ is the standard refrigerant for these installations. As of 2013, CO₂ systems have been installed in 35 percent of its stores.¹²⁹

Since 2008, Migros has also been installing transcritical CO₂ systems with integrated parallel compression technology for higher energy efficiency.¹³⁰ The systems reduce thermodynamic losses that otherwise occur during periods of high ambient temperature through multi-stage compression and decompression.¹³¹ Swiss-based manufacturers Frigo-Consulting Ltd. who installed such a system in 2011 in Migros' Ebikon store reported energy savings of up to 10,000

kWh during the first year.¹³² The evaporation temperature can be increased to around -1.5°C (29°F), an improvement on standard booster system which has evaporation temperatures of 8°C (46°F).¹³³ As the ambient temperature rises, the energy efficiency of these models increases.¹³⁴

About Migros: Established in 1925, Migros is the largest retailer in Switzerland, and as of 2013 had 610 in-country stores, as well as stores in Germany and France.¹³⁵

About Carrier Corporation: See above Tesco case study.

About Frigo-Consulting Ltd.: Founded in 1988, Frigo-Consulting Ltd. is headquartered in Bern, Switzerland and is a manufacturer of commercial and industrial refrigeration systems, with a large focus on transcritical CO₂ technology.¹³⁶



Frigo-Consulting Parallel Compressor System¹³⁷

Royal Ahold CO₂/HFC hybrid installations and transcritical CO₂ pilot systems (Europe)

As of 2013, Royal Ahold had 227 CO₂/HFC hybrid systems across its estate, with a large reliance on HFC-134a as the secondary refrigerant. However, Royal Ahold has announced that it plans to phase out all HFCs in its stores within the next 15 years.¹³⁸ Royal Ahold is currently trialing three HFC-free stores, installing transcritical CO₂ systems at its



Carrier MaxiCO₂ OL Refrigeration System
Image courtesy of Shecco

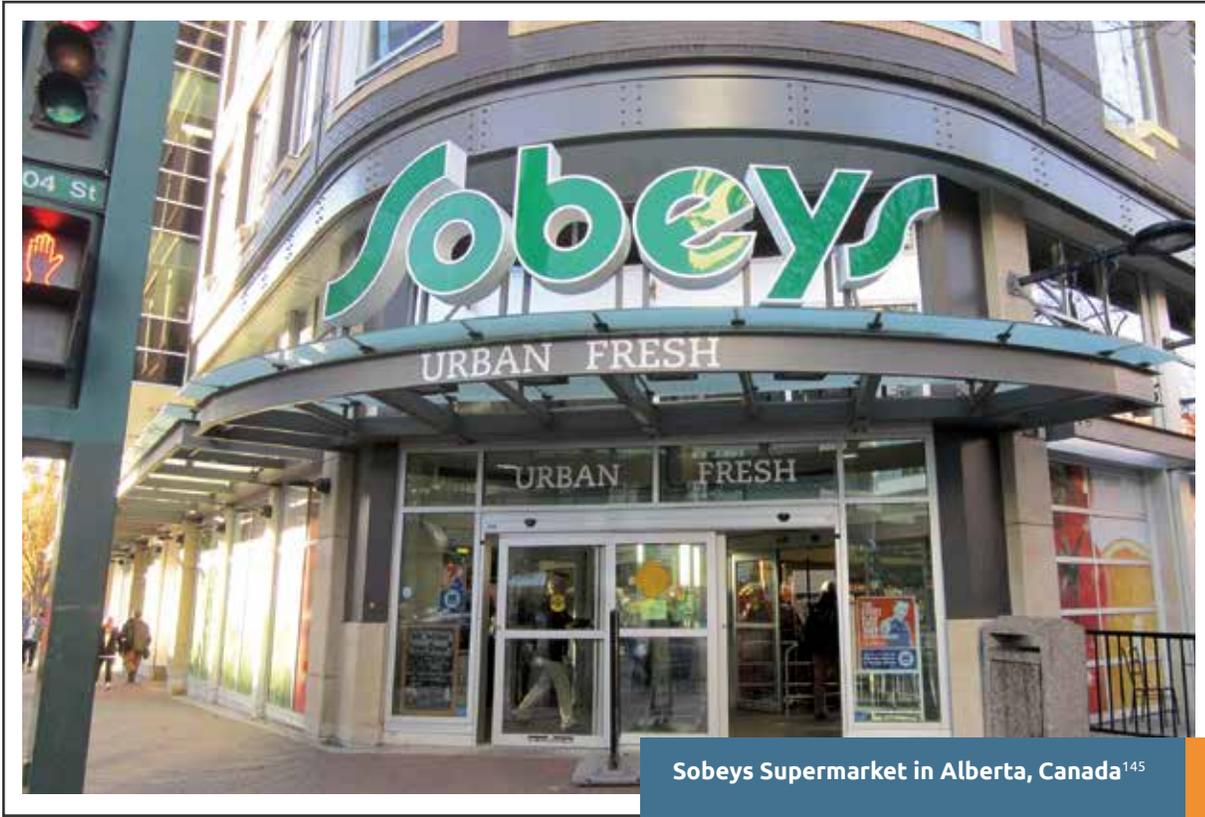
Dutch-based Albert Heijn stores. If these pilots prove successful, transcritical CO₂ systems will be rolled out across most of Royal Ahold's estate by 2023.¹³⁹ According to Royal Ahold, the CO₂OLtec systems, manufactured by Carrier Corporation have reported total greenhouse gas emission reductions of approximately 3,629 tonnes of CO₂ annually compared to conventional store CO₂/HFC hybrid systems.¹⁴⁰

About Royal Ahold: As of 2013, Royal Ahold had approximately 3,000 stores worldwide, including 881 stores in the Netherlands, with a number of stores in Belgium, Germany, Slovakia, the Czech Republic, and the U.S.¹⁴¹ Royal Ahold builds a reported 150 new stores per year.¹⁴² In 2011, the company had over 122,000 employees and reported revenues of U.S. \$39.1 million.¹⁴³ In 2013, Royal Ahold sold its share in ICA where CO₂ had already been installed at 50 locations in Sweden.¹⁴⁴

About Carrier Corporation: See above Tesco case study.

Sobeys Transcritical CO₂ Systems (Canada)

As of February 2014, Sobeys had already installed transcritical CO₂ systems in 65 stores with a minimum of six stores in the planning stage for



Sobeys Supermarket in Alberta, Canada¹⁴⁵

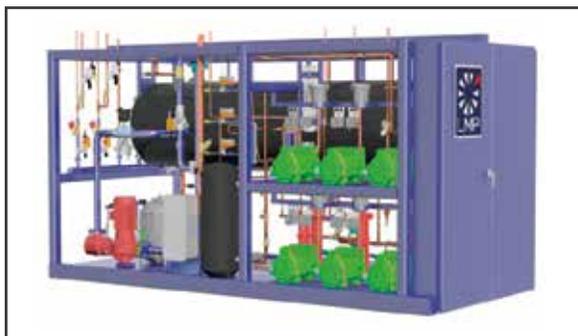
conversion to similar systems during the remainder of 2014.¹⁴⁶ In 2010, Sobeys instituted a national initiative focused on finding the most optimal refrigeration system, and transcritical CO₂ was selected because of its significant energy and climate benefits when compared to HFC systems. The transcritical CO₂ systems cost 10 percent less to install due to less copper and only one pipe size, decrease maintenance costs by 50 percent, deliver 94 percent savings in refrigerant costs, use 15 percent less energy while reducing heating bill costs by 75 to 85 percent, which all leads to an overall 99 percent reduction in Sobeys's greenhouse gas emissions.¹⁴⁷ Sobeys has worked with four suppliers – Carnot Refrigeration, Systems LMP, and Hillphoenix Advansor.¹⁴⁸

About Sobeys: Sobeys was founded in 1907 in Nova Scotia, Canada and has over 1,569 stores with approximately 47,000 employees.¹⁴⁹ Sobeys had only one transcritical CO₂ system in 2009, and in just five years has installed CO₂ systems in 65 stores, more than all other North American retailers combined.¹⁵⁰

About Carnot Refrigeration: Since 2008, Carnot Refrigeration of Trois-Rivieres, Quebec has developed commercial and industrial systems that reduce the environmental impact of refrigeration with designs based around CO₂ and cascade CO₂/ammonia systems.¹⁵¹ The company has been involved in numerous applications of transcritical CO₂ systems throughout Canada and the U.S. Carnot recently joined the U.S.¹⁵² EPA's Greenchill Partnership, which is a program designed to promote alternatives to HCFC and HFC supermarket technologies, reduce synthetic refrigerant leakage, and improve energy efficiency in refrigeration at commercial retail stores.¹⁵³ Carnot's transcritical CO₂ systems have a capacity of up to 2,000 kW and use half the space of synthetic gas systems. They also have heat recovery potential for heating air and water, and obtain energy savings of up to 25 percent and require reduced maintenance, resulting in reported operating cost savings of up to 31.5 percent.¹⁵⁴

About Systems LMP: For over 15 years, Systems LMP has manufactured custom refrigeration and heat recovery systems and feature several transcritical CO₂ refrigeration systems for industrial and commercial installations.¹⁵⁶ The Purity Module transcritical CO₂ system uses patented dedicated compressors for heat recovery and patented compressor lubrication management in order to minimize operating costs and maximize efficiency.¹⁵⁷ As of October 2013, Systems LMP has been part of six transcritical CO₂ system installations and one cascade system, in addition to eight more units in the process of being installed at the time.¹⁵⁸

About Hillphoenix Advansor: See above Carrefour case study.



Systems LMP Purity CO₂ Module¹⁵⁵

Delhaize Transcritical CO₂ Store (U.S.)

In 2013, Delhaize group opened the first 100 percent CO₂ store in the U.S. in Maine under its Hannaford brand.¹⁶⁰ The Hannaford store features a Carnot Refrigeration transcritical CO₂ booster for low temperature and medium temperature with glycol heat reclaim and warm gas defrost systems.¹⁶¹ The system has a low temperature capacity of 76 kW/hr and a medium temperature capacity of 263 kW/hr and expected to be 5 to 10 percent more energy efficiency than Hannaford's HFC-based systems.¹⁶²

About Delhaize Group: Delhaize group has operations in the United States, Belgium, southeast Europe, and Asia.¹⁶³ In 2012, Delhaize Group

achieved revenues of U.S. \$31.47 billion.¹⁶⁴ As of 2013, Delhaize Group had 40 stores using HFC-free refrigeration, with further use of hydrocarbon plug-in systems in Romanian stores.¹⁶⁵



Carnot Transcritical CO₂ System¹⁵⁹

About Carnot Refrigeration: See Industrial Refrigeration Section.

Walgreens Transcritical CO₂ Store (U.S.)

In 2013, Walgreens opened a store in Illinois, U.S. using a Green & Cool transcritical CO₂ geothermal cooled heat pump system that utilizes ground water to heat and cool the store space and help increase the refrigeration systems efficiency for cooling and freezing the store's display cabinets.¹⁶⁷ The system provides the store with heating, hot water, the cooling load high temperature, the cooling load medium temperature, and the freezer load low temperature.¹⁶⁸ The transcritical CO₂ system combined with a geothermal unit yields 2.5 times the cooling efficiency and 5 times the heating efficiency¹⁶⁹, leading to energy savings over 60 percent compared to a traditional system.¹⁷⁰ The combination of transcritical CO₂ with geothermal systems has the potential to greatly increase energy efficiency of CO₂ systems throughout all climates.¹⁷¹ In addition to the transcritical CO₂ geothermal cooled heat pump system, the store has over 800-265 watt solar panels and two 2000 watt wind turbines, generating around 219,000 kWh from solar and wind power, which makes the store a net zero energy store as it only consumes about 200,571 kWh.¹⁷² In



Walgreens Transcritical CO₂ Net-Zero Energy Store in Evanston, Illinois¹⁶⁶

addition to using a Green & Cool transcritical CO₂ system, Walgreens worked with Trane, Geothermal International, and CTA Group to make the air-conditioning and refrigeration system possible.¹⁷³

About Walgreens: Walgreens Company, founded in 1901 in Chicago and headquartered in Illinois, U.S. is the largest drug retailing chain in the U.S. with 9,206 stores as of January 2014.¹⁷⁴

About Green & Cool: Green & Cool, headquartered in Sweden, is a supplier of refrigeration systems that use CO₂ as a refrigerant.¹⁷⁶ Since 2007, Green & Cool products have been distributed worldwide.¹⁷⁷



Green & Cool's Crystal Double Temperature System¹⁷⁵

About Trane: Trane (subsidiary of Ingersoll Rand) is a global provider of heating, ventilating, and air-conditioning systems headquartered in New Jersey, U.S.¹⁷⁸

About Geothermal International: Founded in 2001, Geothermal International is market leader in the UK in large-scale ground source heat pump solutions.¹⁷⁹ Geothermal International recently acquired Endurant Energy, which is a U.S. based company.¹⁸⁰ The company focuses on feasibility

studies and energy master planning, engineering and system design, consulting, development and construction, commissioning and optimization, and comprehensive lifecycle service.¹⁸¹

About CTA Group: CTA Group provides integrated design and engineering solutions for refrigeration systems.¹⁸² CTA was part of the first all-natural refrigeration system installation in the U.S., the Albertson's Carpinteria store, which uses a cascade CO₂/ammonia system.¹⁸³

Verdemar Supermarket Cascade CO₂/HFC-134a System (Brazil)

Verdemar Supermarkets was the first to install a refrigeration system using CO₂ as a refrigerant in Latin America. Verdemar is a smaller retailer, with the 6,000 m² (64,580 ft²) Minas Gerais store being the company's fifth store.¹⁸⁴ The system was installed by Plotter & Racks and uses CO₂ for low temperature (36 kW capacity at -32°C), propylene glycol for medium temperature (200 kW capacity at -2°C), and a reduced charge of HFC-134a for high temperature.¹⁸⁵ In total, the Skyrack Breeze system emits six times less greenhouse gases than conventional technologies that use HFC-404a.¹⁸⁶ The refrigeration unit features a heat recovery system, a condensing temperature reduction system, condenser fans with direct-current and variable speed, electronic expansion valves, variable frequency driver compressors, and electronic controllers for optimal system operation.¹⁸⁷ These features improve the overall efficiency of the system resulting in many benefits. The system



Verdemar Supermarket in Minas Gerais, Brazil¹⁸⁴

delivers 20 to 30 percent less energy consumption, low compression ratio and increased life expectancy of the Bitzer CO₂ compressor, reduction of CO₂ piping sizes and refrigerant charge size, low costs for CO₂ refrigerant, smaller refrigeration rack, compact installation and overall reduced installation and maintenance costs.¹⁸⁸

About Verdemar Supermarkets: Operating since 1993, Verdemar retails in six locations throughout Brazil.¹⁸⁹ The company has adopted cascade systems as a standard and has announced that it will be installing 100 percent natural HFC-free systems in the near future.¹⁹⁰ Verdemar currently has two stores using natural refrigerants.¹⁹¹

About Bitzer Brazil: Bitzer, as described above in the New World case study in New Zealand, has been in the business of manufacturing compressors, condensing units, and pressure vessels for more than 75 years.¹⁹² Bitzer Brazil is recognized as one of the largest developers of CO₂ technology in South America and has its own CO₂ training course and center, which focuses on: CO₂ fundamentals, systems safety with CO₂ applications, CO₂ system components, and commissioning, servicing, and maintenance procedures.¹⁹³ Bitzer Brazil also built South America's first transcritical CO₂ system, in its training center in order to provide hands on training for technicians.¹⁹⁴

About Plotter & Racks: Plotter Engenharia, based in Curitiba, Brazil, has offered services in the

field of industrial and commercial refrigeration projects, including supermarkets, hypermarkets, convenience stores, distribution centers and production plants for over 15 years.¹⁹⁵

Marks and Spencer Hydrocarbon Refrigerant Stores (UK)

In 2012, Marks and Spencer opened a store in Cheshire Oaks, UK featuring a hydrocarbon refrigeration system.¹⁹⁷ The hydrocarbon compressor pack works with distributed CO₂ to serve all the frozen and chilled food cases and the cold room.¹⁹⁸ Designed by A1 Refrigeration and Emerson Climate Solutions, the refrigeration system employs a number of innovative measures leading to energy efficiency levels greater than 40 percent above that of conventional synthetic gas refrigeration systems.¹⁹⁹ The same year, Marks and Spencers also opened its Stratford City store at the site of the 2012 London Olympics. This three level store features a hydrocarbon refrigeration plant providing cooling to 99 percent of refrigeration systems and cold rooms.²⁰⁰

The installation of displacement ventilation columns bring cooler outside air in and collect rising warm air, helping to reduce the overall carbon impact.²⁰¹ These developments helped allow Marks and Spencer to become the first major carbon neutral retailer in the UK and Republic of Ireland, a figure which extended beyond stores to offices,



Marks & Spencer in Cheshire Oaks, UK¹⁹⁶

warehouses and delivery fleets.²⁰² From 2006 to 2012, the company reduced overall emissions from its store refrigeration systems by 60 percent.²⁰³ Despite a previous commitment to go HFC-free in all new systems the retailer has opted for HFC/CO₂ hybrids in recent stores, however it is re-trialing transcritical CO₂ systems with a plan to utilize these completely HFC-free technologies if the new designs are more energy efficient and require less maintenance than its hybrid systems.

About Marks and Spencer: Marks and Spencer products are sold in 766 UK and 418 stores in Europe, the Middle East and Asia.²⁰⁴ As of 2013, the company had 76 stores running on alternative refrigerants. While these were mostly HFC/CO₂ hybrid systems, the company has increased its volume of natural refrigerants used to 20 percent of total refrigerants.²⁰⁵

About A1 Refrigeration: A1 Refrigeration Group provides refrigeration, air-conditioning and building services solutions to commercial, retail and industrial applications throughout the UK.²⁰⁶

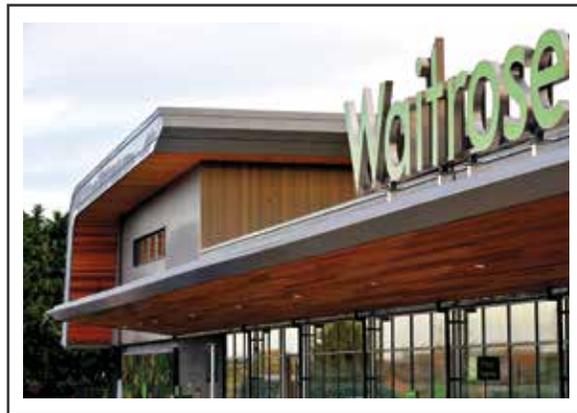
About Emerson Climate Solutions: See NewWorld's case study above.

About Carrier Corporation: See above Tesco case study.

Waitrose Hydrocarbon Water-Cooled Display Units (UK)

Waitrose is using water-cooled equipment with propane as the refrigerant to decrease the total volume of refrigerant used. The systems have small display units that are connected to a water loop in order to remove heat and reduce the refrigerant charge by up to 90 percent.²⁰⁷ Manufactured by Geoclima, the systems use split coils to keep the refrigeration charge below 400 grams of hydrocarbons, with the combined use of liquid pump amplification and floating head pressure to keep free-cooling below 18°C (64°F).²⁰⁸

The system was first introduced into the Altrincham store in 2009, and has since been rolled-out across all of Waitrose's new stores and stores that have undergone major retrofits.²¹⁰ The stores have reduced energy consumption by 20



Waitrose Supermarket in Bracknell, UK²⁰⁹

percent and their carbon footprint reduction of more than 50 percent when compared to an HFC-refrigerated store.²¹¹

About Waitrose: Waitrose is owned by the John Lewis Partnership, who employ almost 68,000 employees.²¹² In 2014, Waitrose had over 280 branches in the UK.²¹³ It has annual revenues of over U.S. \$10.1 billion.²¹⁴

About Geoclima: Founded in 1994, Geoclima designs and develops chillers for air-conditioning and refrigeration system applications.²¹⁵ Based in Italy, the company produces around 500 units worldwide each year.²¹⁶

The Co-op Hydrocarbon Integrals (UK)

Co-op UK is continuing its roll-out of hydrocarbon installations in order to reduce its use of fluorinated refrigerants. Co-op UK currently has hydrocarbon units installed in 2,400 stores, equating to nearly 20 percent of the total refrigerant it uses.²¹⁷ In 2012, emissions from refrigerant and air-conditioning systems accounted for 14 percent of the company's direct carbon footprint.²¹⁸ To help enable the transition to lower greenhouse gas emissions from refrigerants and higher energy efficiency, Co-op UK is investigating a range of innovative technologies for convenience stores, including hydrocarbon refrigeration packs that include in-store heat recovery systems.²¹⁹



The Co-operative Food UK
Image courtesy of The Co-operative

About the The Co-operative: The Co-operative is the UK's largest mutual business, ownership of which is shared between nearly eight million members. The Co-operative Food is one of nine businesses which the group operates and the UK's fifth biggest retailer, with a food store in every UK postal area.²²⁰ The UK branch has over 2,800 retail outlets and employs almost 75,000 people.²²¹

H-E-B Hydrocarbon Refrigeration System (U.S.)

In 2013, H.E. Butt Grocery Company (H-E-B) opened a 7,710 m² (82,990 ft²) store in Austin, Texas using a Hussmann designed micro-distributed propane refrigeration system.²²² The system is equipped with Tecumseh Products Company AE² series high efficiency compressors in almost half the units, with the majority of units containing water cooled condensers and evaporators, which allows the charge size of the propane to remain under the mandated 150 grams charge size.²²³ Embraco compressors are installed for low temperature reach-in cases and Copeland compressors are used for walk-in unit coolers.²²⁴ H-E-B praises the system as being easy to install, as the system is delivered fully built from the factory, installed on-site and will last for at least 15 to 20 years.²²⁵ In addition to reducing up to 1,556 tonnes of CO₂e annually as a result of switching to propane as its refrigerant²²⁶, H-E-B is predicting that the system

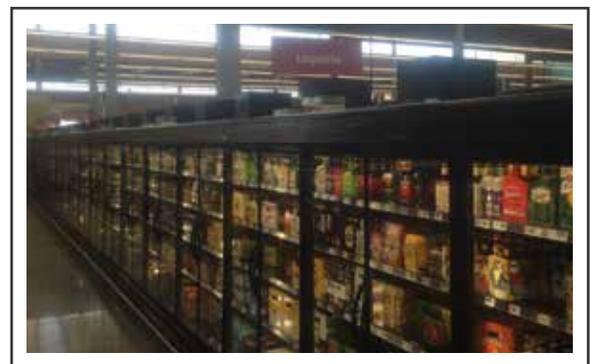


HEB Supermarket Austin, Texas
EIA

will be 50 percent more energy efficient than one of its typical stores. Projections from its first year of operation document that the system is actually operating with an impressive 79 percent improved efficiency.²²⁷ The propane system refrigerates nearly 90 percent of the store (meat, dairy, produce and frozen display cases), with a small amount of HFC-404a is still used.²²⁸

About H-E-B: H-E-B opened up its first store in 1905 in Kerrville, Texas and now has 340 stores in Texas and Mexico and over 76,000 employees.²²⁹

About Hussmann: Since 1906, Hussmann Corporation has provided refrigerated products



Hussmann Micro-Distributed Propane System at HEB
EIA

and solutions and is currently a worldwide leader in manufacturing, selling, installing, and servicing display equipment and refrigeration systems for customers in the retail food industry.²³⁰ Hussmann has operations throughout the U.S. and Canada, Latin America, and the Asia/Pacific region.²³¹

About Tecumseh: Since 1937, Tecumseh Products Company has developed hermetic compressors for refrigerators.²³² Today, Tecumseh manufactures compressors and condensing units that use hydrocarbon refrigerants (propane and isobutane) and are sold worldwide with demand steadily growing.²³³ In 2013, Tecumseh decided to expand



Tecumseh AE2 Compressor

Image courtesy of Shecco

its manufacturing operations in Mississippi to meet the increase of demand in response to rising global demand for Tecumseh's AE² compressor.²³⁴ The compressor is reported to be the most efficient compressor of its size on the market, and is available for use in beverage and other standalone coolers, as well as in commercial refrigeration.²³⁵

About Copeland (Emerson Climate Technologies): See above New World case study.

About Embraco: See Domestic Refrigeration Section.

True Manufacturing Under-counter Hydrocarbon Units (Europe)

True Manufacturing's TUC-24-HC under-counter units use propane (HC-290) as its refrigerant, which provides for environmentally-friendly refrigeration in small retail commercial applications.²³⁷ The under-counter units are ideal for coffee shops, bakeries, and other small retail stores. In addition to using propane, the unit also uses Ecomate foam for its high density polyurethane insulation. Ecomate manufactures low-GWP alternative foam that

uses methyl-formate, with a global warming potential of approximately 20 and zero ozone depletion potential blowing agent, instead of HFCs.

About True Manufacturing:

True Manufacturing, headquartered in the U.S., is a global provider of refrigeration products with offices in UK, Australia, Mexico, and Germany.²³⁸

Coca-Cola CO₂ Standalone Equipment (Global)

In January 2014, Coca-Cola installed its 1 millionth HFC-free Cooler.²³⁹ By using modern energy efficient CO₂ systems developed by Sanyo, Coca-Cola has prevented 5.25 million tonnes of CO₂ equivalents from being emitted over the last ten years by using HFC-free insulation foam, and prevented 75 percent of direct greenhouse gas emissions.²⁴⁰ Coca-Cola has demonstrated that its CO₂ equipment is more reliable and more energy efficient than HFC-based systems.²⁴¹ The tests found a CO₂ cooler to be 18 percent more energy efficient and a vending machine to be 36 percent more energy efficient.²⁴² The machines have been installed worldwide, with Coca-Cola reporting that 38 percent of its machines are certified for harsh, high ambient conditions.²⁴³

In Japan after the earthquake/tsunami in March 2011 and the resulting nuclear crisis that shutdown part of the country's electricity generating capacity, Coca-Cola revamped its



True Manufacturing TUC-24-HC Under-counter Unit²³⁶



HFC-free CO₂ System in the United States Senate Building

EIA

vending machines in collaboration with Sanden's Peakshift Vending Machines²⁴⁴ to reduce daytime power consumption by 95 percent and overall power consumption by 68 percent compared to conventional machines.²⁴⁵ Coca-Cola is part of the industry organization Refrigerants Naturally!—a global initiative focused on addressing climate change and ozone layer depletion caused by refrigeration equipment.²⁴⁶

About Coca-Cola Company: Coca-Cola Company is one of the world's largest beverage company with over 500 brands.²⁴⁷ The company has a distribution system reaching consumers in over 200 countries.²⁴⁸

About Panasonic/Sanyo: See above Lawson's case study.

About Danfoss: See above in Woolworths case study.

PepsiCo Hydrocarbon Vending Machines (Global)

In 2009, PepsiCo invested in hydrocarbon vending machines, which it has now installed globally and resulted in massive mitigation of HCFC and HFC emissions.²⁴⁹ The new machines show significant energy efficiency improvements, as well as greatly

reduced greenhouse gas emissions. The PepsiCo systems use 20 percent less energy than required by Energy Star for vending machines.²⁵⁰

PepsiCo has also invested in CO₂ cooled machines and those machines have shown 51 percent energy efficiency improvements over 2003 models. Both the hydrocarbon and CO₂ systems use HFC-free foam for insulation.²⁵¹ PepsiCo is also a member of Refrigerants Naturally!²⁵²

About PepsiCo: PepsiCo, headquartered in Purchase, New York, is one of the world's largest food and beverage companies with its products sold in approximately 200 countries.²⁵³



PepsiCo Vending Machine

Image courtesy of Shecco

Red Bull Hydrocarbon ECO-coolers (Global)

As of 2013, soft drinks-manufacturer Red Bull had already equipped at least half of its 1 million coolers globally with hydrocarbon refrigeration systems.²⁵⁴ The ECO-cooler equipment combines the use of propane and isobutane and additional cooling technology equipment, such as specialized fans, resulting in 45 percent less energy consumption than conventional refrigerators.²⁵⁵ As a result of these installations, Red Bull has reportedly reduced overall energy consumption by 20 percent across its entire cooling fleet and prevented the leakage and emissions of HFCs in 400,000 coolers.²⁵⁶ Red Bull is a member of Refrigerants Naturally!²⁵⁷



Red Bull Coolers

Image courtesy of Shecco

About Red Bull: Red Bull was established in Austria in 1984 and is available in more than 165 countries, with sales exceeding 5.2 billion cans per year.²⁵⁸ The brand has recognized that cooling can be responsible for up to 20 percent of its product carbon footprint and have projected plans to phase-out HFCs through the installation of hydrocarbon refrigeration systems in all of its coolers.²⁵⁹

Heineken Hydrocarbon Cooler Installations (Global)

Heineken is continuing its roll-out of HFC-free hydrocarbon coolers. Currently, Heineken has over 800,000 coolers refrigerated with hydrocarbons worldwide, with an additional 130,000 new hydrocarbon based coolers produced each year and has mitigated massive amounts of CO₂ equivalents.²⁶⁰ Approximately 65 percent of the company's refrigeration



Heineken Hydrocarbon Coolers²²²

equipment uses hydrocarbons, with the company reporting a 38 percent increase in energy efficiency over traditional HFC refrigeration equipment.²⁶¹ The company also reports a drop in technology price since the first installations in 2008, helping to lower the costs of the transition.²⁶²

About Heineken: Heineken NV is a Netherlands-based manufacturer of a range of over 250 beer brands worldwide.²⁶³ In 2012, Heineken recorded revenues of U.S. \$43.2 million.²⁶⁴

Ben & Jerry's Ice Cream Hydrocarbon Freezers (Global)

In 2008, Ben & Jerry's introduced ice cream freezers using propane refrigeration systems instead of the traditional HFCs systems into the U.S. market. The new hydrocarbon systems are 10 percent more energy efficient and have greatly reduced direct greenhouse gas emissions.²⁶⁵ Ben & Jerry's, owned by Unilever, has more than 900,000 hydrocarbon freezers in markets throughout the world and has committed that all its U.S. freezers will use hydrocarbon technology.²⁶⁶



Ben & Jerry's Hydrocarbon Freezer²⁶⁷

About Ben & Jerry's (Unilever): Ben & Jerry's, founded in 1978 in Burlington, Vermont, is a producer of ice cream²⁶⁸ and was acquired by Unilever in 2000.²⁶⁹ Unilever is headquartered in London, UK and Rotterdam, Netherlands and has a distribution network that spans over 190 countries with 400 brands.²⁷⁰

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AIR-CONDITIONING

Air-conditioning encompasses a variety of applications and can be categorized into nine different types: factory sealed (moveable systems), single split, multi-split, ducted, small chillers, large chillers, centrifugal chillers, heat pumps, and mobile.¹

Temperature ranges of air-conditioning systems vary from +16°C (+61°F) to +26°C (+79°F) for factory sealed, split systems, multi-split systems, and ducted systems, while chillers have temperature ranges of +5°C (+41°F) to +15°C (+59°F). New technologies used in air-conditioning systems, such as inverter compressors, have been found to have at least a 30 percent increased energy efficiency over conventional fixed speed non-inverter air-conditioners, and in combination with natural refrigerants, systems have greatly improved operating efficiency.³

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Factory Sealed⁴ – Factory sealed systems are primarily for domestic and commercial uses, and include portable units, window units, through-wall units (e.g., hotel rooms and retrofits), and packaged terminal units. A typical system contains hermetically sealed vapor compressors with cooling capacity ranging from 1 to 10 kW, and 300 grams to 3 kg of synthetic refrigerant (average of 0.75 kg).

Single Split⁵ – Split type air-conditioning includes systems for domestic and commercial use that contain a factory-assembled compressor/condenser and a separate indoor evaporator unit that is connected on-site. The cooling capacity of single splits range from 2 to 12 kW with typical synthetic charge sizes between 500 grams and 5 kg (1.5 kg average). Many split systems have the ability to provide heating as well.

Multi-Split⁶ – Multi-split stationary systems are primarily used for commercial air-conditioning and heating with typical system components including one or more factory assembled compressor/condenser units and several separate indoor units joined with interconnecting piping during installation. Capacity ranges from 10 to 200+ kW with typical charge sizes of 5 kg to 100+ kg for holistic systems, while individual units range from 10 to 50 kW with average synthetic charge sizes of 13.5 kg.

Ducted⁷ – Ducted systems include multiple types of air-conditioning systems, including rooftop, centralized, and close-control systems that are used in commercial and domestic cooling and heating applications with cooling capacities ranging from 10 kW to 300 kW using 5 kg to over 150 kg of synthetic refrigerant. System types are designed as follows: Rooftop systems are built with a single compression unit in a packaged system connected through ducts that run throughout the building. Centralized systems have a compressor/condenser unit located outside, delivering refrigerant via piping to a duct-mounted evaporator within the building. A closed control system is based on a direct expansion system with an outside compressor/condenser

unit or with an internal compressor and outside condenser, or with the entire compression system using a water-cooled condenser.

Chillers⁸ – Chillers vary in size from small (10 to 350 kW, 5 to 100 kg synthetic charge) to large chillers (>350 kW, >1,000 kg synthetic charge) to centrifugal chillers (200 kW to 20 MW, 100 kg to 10,000 kg synthetic charge) and cover both air-cooled and water-cooled systems. Systems are used primarily in commercial and industrial applications and are comprised of a factory assembled evaporator/compressor/condenser unit with certain air-cooled systems having a separate outside condenser. Wherever there is waste energy (e.g., heat, steam, gas, hot water), such as at plants, factories, breweries, bakeries, and landfills, adsorption chiller systems can utilize the waste energy for cooling applications.⁹

Heat Pumps¹⁰ – Heat pumps are used in domestic, commercial and industrial applications and work to remove heat from sources, such as the water, ground, or air, which it then supplies to a water-circuit within a building for space and water heating. System designs vary with products primarily made of a factory assembled evaporator/compressor/condenser unit that is connected to a pre-installed water circuit on-site, while some air-source models use an outside condenser that is connected on-site. Capacity ranges from 5 kW to 50 kW with some commercial units exceeding 400 kW and synthetic refrigerant charges of 1.5 kg to 15 kg (much more in large commercial/industrial units).

Mobile¹¹ – Mobile air-conditioning applications include: passenger cars, light and heavy trucks, buses, cargo ships, passenger ships, cruise ships, and rail vehicles. For road vehicles, the system compressors are driven by the vehicle’s engine belt with only a single evaporator used in most applications, except for some luxury cars and bus systems, which are comprised of two or more evaporators. Passenger cars and light trucks have synthetic charge sizes ranging from 400 to 800

grams, the charges in heavy trucks range from 0.7 to 1.5 kg, vehicles with two evaporator systems have more than 1.8 kg synthetic charge sizes, and, the charges in buses range from 6 to 18 kg. Cargo ships have average synthetic charge sizes of 150 kg and use split systems with direct refrigerant evaporation in combination with a condensing unit consisting of a compressor and condenser, which keeps crew cabins cool. Passenger ships have average synthetic charge sizes of 500 kg and use indirect systems with water chillers. Cruise ships have refrigeration capacity of up to 15 MW provided by large water chillers with synthetic charges of about 6,000 to 7,000 kg. Rail vehicles (rail cars, metro, tram) air-conditioning systems are comprised of four main types: compact roof, compact under-floor, split, and compact central. Refrigerating capacity varies by climatic zones with around 20 to 40 kW on average in the EU and synthetic charge sizes between 5 and 30 kg (average 13 kg), while capacity for driver’s cabins is 3 to 8 kW with synthetic charges of 1.5 to 4 kg.

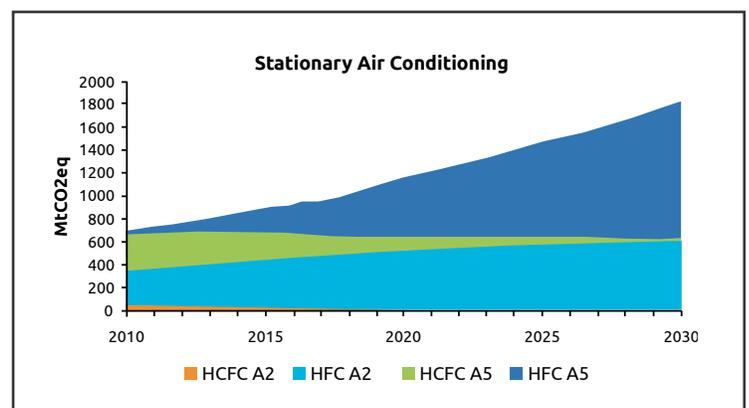


Figure 1: Global BAU Consumption of HCFCs and HFCs from Stationary Air-Conditioning (A2 = Developed Countries A5 = Developing Countries)¹

As seen in Figure 1, stationary air-conditioning HFC consumption is projected to increase significantly and would be the largest consumer of HFCs out

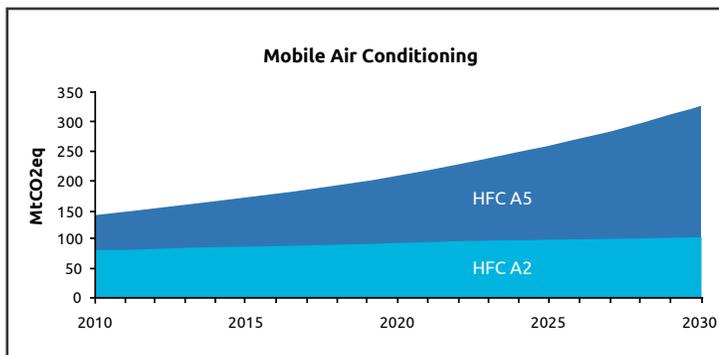


Figure 2: Global BAU Consumption of HFCs (HFC-134a) from Mobile Air-Conditioning of Road Vehicles (A2 = Developed Countries A5 = Developing Countries)¹¹

of all the sectors if a business as usual trend occurs. The average lifetimes of air-conditioning equipment range from 10 to 25 years.¹² Therefore, it is critical that countries and companies transition to energy efficient, low-GWP HFC-free systems, instead of energy wasting equipment using climate-destroying HFCs. HFC-free natural refrigerants used in air-conditioning are CO₂, ammonia, water, air, and hydrocarbons depending on the size and use of the air conditioners. Solar air-conditioning units used in combination with HFC-free refrigerants are also available and can play an important role in reducing energy consumption and mitigating carbon pollution. HFC-free systems are energy efficient, cost effective, and climate-friendly and have been applied across all latitudes and in all climates.

Case studies of some of these HFC-free technologies for air-conditioning are set forth below:

DOMESTIC AIR-CONDITIONING

De'Longhi Pinguino Portable Hydrocarbon Air-Conditioners (Global)

Since 1995, De'Longhi, an Italian small appliance manufacturer, has been producing a range of hydrocarbon domestic air-conditioners for the European market.¹³ De'Longhi portable air-conditioners include a variety of units for varying room sizes. De'Longhi has four units that use propane (HC-600a) as the refrigerant. The Pinguino

PAC W ECO units have energy savings of between 15 and 20 percent.¹⁴

About De'Longhi: De'Longhi Group, incorporated in 1950, is a major small appliance manufacturer based in Treviso, Italy. As of 2012, it had sales totaling about U.S. \$2 billion.¹⁶ De'Longhi has operations across Europe, Asia, Australia, New Zealand, Dubai, South Africa, Brazil, Chile, U.S., and Canada.



Pinguino PAC W ECO¹⁵

Godrej Green Balance EON Hydrocarbon Range (India)

Godrej's Green Balance EON range of 5-star air-conditioners, use hydrocarbons as the refrigerant and exceed the energy savings rating specified by the Bureau of Energy Efficiency (BEE) for 2014 standards.¹⁷ Godrej reports that the new product saves 23 percent more energy than other 5-star products currently on the market.¹⁸ Godrej asserts the system uses less energy than a hair dryer, iron, or a blender.¹⁹

About Godrej: Headquartered in Mumbai, India, Godrej Group's Appliance Division was established in 1958 and manufactures refrigerators and air-conditioners, along with several other home appliances and electronics.²⁰ Godrej Appliances has a sales distribution network throughout India.²¹



Godrej Eon Split AC System
EIA

Gree Hydrocarbon Room Air-Conditioners (China, Global)

In 2011, Gree, the largest air-conditioner manufacturer in China, opened a 100,000 unit/year production line of propane room air-conditioners at its facility in Zhu Hai.²² The system greatly reduces greenhouse gas emissions by using propane which has a GWP of 3.3 compared to HCFC-22 with a GWP of 1,800 or HFC-134a with a GWP of 1,430. In addition to significantly lowering refrigerant charge sizes and leakage rates, this propane air conditioner achieves energy efficiency gains of up to 15 percent compared to conventional systems.²³ Gree, in cooperation with German GIZ Proklima has agreed to convert 18 production lines to manufacture propane air conditioners, which is currently being implemented.²⁴



Gree Hydrocarbon Air-Conditioner
EIA

About Gree Electric Appliances, Inc. Of Zhuhai:

Gree is one of the largest specialized air-conditioner companies in the world with its headquarters in Zhuhai, China and six production centers located in Chongqing (China), Heifei (China), Brazil, Pakistan and Vietnam.²⁵ Gree's annual capacity is over 27 million residential air-conditioners and 2 million commercial air conditioners.²⁶

Midea Hydrocarbon Air-Conditioners (China, Global)

Midea's propane air-conditioner production line of 200,000 units/year is an official United Nations Industrial Development Organization (UNIDO)

Implementation Project.²⁸ Midea has found that the amount of refrigerant needed when using propane is 30 to 40 percent less than HCFC-22.²⁹ The system's energy efficiency has been improved by 10 to 15 percent and nearly 1 million tCO₂e will be saved annually from the Midea facility conversion.³⁰ The project also phases-out 240 tonnes of HCFC-22 (13.2 tonnes of ozone depletion potential) annually.³¹ Midea's development and transition towards hydrocarbon systems is significant given the company manufactures one out of four of the world's split-type air-conditioners.³²



Midea Air-Conditioner²⁷

About Midea: Midea has operations and production bases in China, Vietnam, Belarus, Egypt, Brazil, Argentina, and India, and is rapidly expanding its distribution network throughout the world.³³

Pioneer International Hydrocarbon Split and Ducted Air Conditioners (Global)

Pioneer International's hydrocarbon split and ducted air conditioners are 35 percent more energy efficient than standard inverter units.³⁵ Pioneer has found hydrocarbon refrigerants to be about 50 percent more efficient heat conductors, in addition to maintaining 25 percent less operating pressures than fluorocarbon refrigerants.³⁶ Lower operating pressures reduce wear and tear on the compressor and decrease the likelihood of leaks, as a lower operating pressure is better for the integrity of pipe work, joints, and fittings in the system.³⁷ Pioneer air-conditioner units using hydrocarbon



Pioneer Hydrocarbon Air-Conditioners³⁴

refrigerant blends by Engas are estimated to be about 10 percent less costly than equivalent fluorocarbon systems.³⁸

About Pioneer International: Pioneer International is based in New South Wales, Australia and has been manufacturing air-conditioners for over two decades.³⁹ It was one of the first companies to develop a solar powered air-conditioner, however an HFC-free solar system is still in development.⁴⁰ Pioneer recently added an international component in order to make its products available around the world.⁴¹

About Engas: Engas, headquartered in Perth, Australia, is an environmental and energy efficiency company specializing in hydrocarbon refrigerants.⁴² These refrigerants can be used for medium temperature, medium to low temperature, low temperature, and special applications, such as drop in replacements.⁴³

COMMERCIAL AND INDUSTRIAL AIR-CONDITIONING

York Hydrocarbon Chiller (Singapore)

In 2005, Singapore's Far East Shopping Mall converted its old HCFC-22 chiller to a hydrocarbon York 200TR water-cooled chiller bringing energy efficiency improvements of 16 percent.⁴⁵ The conversion involved five 700 kW capacity York 200TR air-cooled chillers using a charge of about 25 kg of "ERG Minus 50" (hydrocarbon



Far East Square Mall York Chiller⁴⁴

refrigerant blend of propane and propylene).⁴⁶ The conversion project by Energy Resources Group of Australia was part of more than 70 hydrocarbon conversion projects throughout Asia, including Singapore, Malaysia, Thailand, Indonesia, and the Philippines.⁴⁷ The projects used a variety of systems manufactured by Gree, Mitsubishi, Carrier, Sanyo, York, Hitachi, General, McQuay, Dunham-Bush, Acson, and other manufacturers. Conversions achieved energy savings of from at least 12 to 50 percent. At the Sahid Jaya Hotel in Lombok, Indonesia, the conversion to a hydrocarbon chiller resulted in a 72 percent energy savings.⁴⁸

About York (Johnson Controls): York, owned by Johnson Controls, is an independent supplier of heating, ventilating, air-conditioning and refrigeration (HVAC&R) equipment. See Transport Refrigeration section for details of Johnson Controls.

Hydrocarbon Chiller in Healthcare Center (Denmark)

In 2012, a refurbished propane air-cooled chiller system was installed at a 4,450 m² (47,900 ft²) healthcare center in Brørup, Denmark.⁴⁹ Manufactured by Bundgaard Kølleteknik A/S with Frascold compressors, the system includes air-cooled condensers for indirect cooling and ethylene glycol (30 percent) for the secondary side, a hydro-station with a reservoir tank, and a distribution pump supplying the 13 ceiling cassettes with 4-ways air throw, and a brazed plate heat exchanger for the ventilation unit.⁵⁰

About Bundgaard Køleteknik A/S: Founded in 1952, Bundgaard Køleteknik A/S is a manufacturer of air- and water-cooled chillers, as well as air-to-water and water-to-water heat pumps using propane as the refrigerant.⁵¹ The company specializes in hydrocarbon systems and its customizable chillers and heat pumps can be installed in a number of applications, including large offices and production plants, swimming pools, stables and farms.⁵²

About Frascold: For over 70 years, Frascold of Italy has produced compressors for the refrigeration and air-conditioning industry with a global sales network.⁵³ Currently, the company produces more than 70,000 compressors annually for air- and water-cooled condensing units.⁵⁴ Frascold has a number of compressors and condensing units for various applications, including: semi-hermetic compressors, two-stage semi-hermetic compressors, tandem semi-hermetic compressors, compact twin screw semi-hermetic compressors, twin screw semi-hermetic compressors for remote oil separators, CXHO innovative twin screw compressors, and air- and water-cooled condensing units.⁵⁵

University of the West Indies Hydrocarbon Refrigeration (Jamaica)

The Mona Campus of the University of West Indies in Jamaica converted its central, window, and mini-split air-conditioning units from HCFC-22 to Duracool 22a (propane).⁵⁶ The University's conversion of 646 units (1,282 tonnes) has resulted in 15 to 20 percent increase in energy efficiency and estimated savings of 350,093 kW/h (U.S. \$96,000) annually.⁵⁷ Along with significant improvements in energy efficiency, the hydrocarbon systems require less maintenance and repair, which add to the cost benefits of the conversion.⁵⁸

About Duracool: Duracool is a Canadian based company that supplies hydrocarbon refrigerants and its products are distributed by Deepfreeze Refrigerants Inc.⁵⁹

ABN Amro Data Center Water/CO₂ (UK)



ABN Amro Data Center⁶⁰

In 2006, Dutch Bank ABN Amro partnered with Star Refrigeration to build a CO₂ based air-conditioning system in order to cool hardware and prevent servers from overheating.⁶¹ The two-stage facility is composed of a condenser, 15 ventilator units, heat exchangers, and gravity flow pumps.⁶² CO₂ is re-condensed with water using an indirect chilling cycle at 6°C (43°F), before ventilator units at the back of the server cabinets provide cooling of the air.⁶³ CO₂ is reported to be the suitable refrigerant for IT climate control because it does not conduct electricity, therefore increasing the safety of the operation. Its high effectiveness also allows for compact cabinet fittings, resulting in space savings of more than 50 percent over conventional systems.⁶⁴ In addition, energy savings are said to be around 30 percent compared to pure cold-water cooling systems.⁶⁵ The installation of an automated CO₂ leak detector help to reduce leakage rates in this high-pressure system.⁶⁶

About Dutch Bank ABN Amro: Dutch Bank ABN Amro works with 15 high-performance servers at its London-branch data center.⁶⁷ The Dutch Bank ABN Amro provides banking services throughout Europe and Asia.⁶⁸

About Star Refrigeration: See Industrial Refrigeration section.

Nestle Plug and Play Ammonia Chillers (Angola, Tunisia, Zimbabwe)



Axima Refrigeration Plug & Play Chiller⁷³

At Nestle's plants in Angola, Tunisia, and Zimbabwe, ammonia plug and play chillers for air-conditioning have been installed by Axima Refrigeration of France.⁶⁹ Nestle installed four 70 kW systems in Zimbabwe, two 90 kW systems in Angola, and two 115 kW systems in Tunisia.⁷⁰ In addition to the massive reduction in emissions of HFCs, due to its increased energy efficiency, each system achieves a carbon footprint reduction of 12 tonnes CO₂/year compared to an HFC-134a chiller.⁷¹ The FrigoBox

chiller by Axima installed at Nestle's factories uses ammonia and water as refrigerants keeping the ammonia charge at 3 kg.⁷² The Frigobox system can also be installed with an air condensation unit, as well as a water condensation system.⁷³

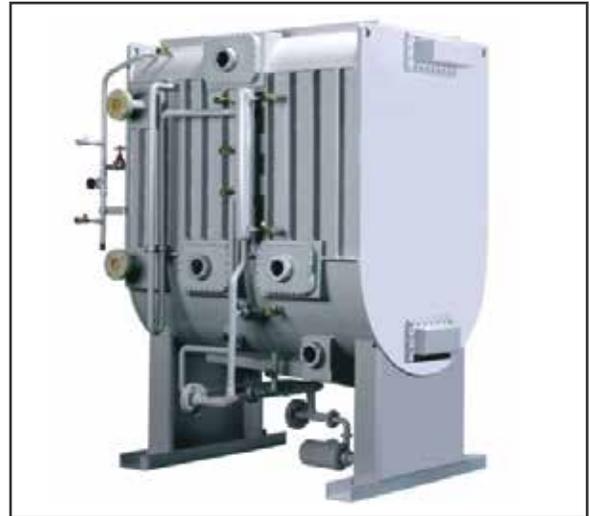
About Nestle: See Industrial Refrigeration Section.

About Axima: See Industrial Refrigeration Section.

Mayekawa Transcritical CO₂ Water Chillers and Ammonia Chillers (Global)

MAYEKAWA CO₂ ADSORPTION WATER CHILLERS

Mayekawa's AdRef-Noa adsorption water chiller produces chilled water from hot wastewater and has a high COP of 10.⁷⁴ Using water as its refrigerant, the system significantly lowers CO₂ emissions. The system is efficient, running on less than 1 kW of electricity while producing 105 kW of cooling capacity.⁷⁵ The chiller uses a new absorbent called zeolite and features two identical adsorption/desorption heat-exchanging sections.⁷⁶ In 2012, the system was installed at Waseda Setsuryou Junior High School in Ibaraki, Osaka prefecture, Japan, in



AdRef-Noa Adsorption Chiller⁷⁴

combination with a solar thermal unit that drives the system, resulting in an overall reduction of electricity by 42 percent for cooling and 73 percent for heating.⁷⁷ The system has also been installed in Guanajuato, Mexico at Gamesa of PepsiCo, which is one of the largest food and beverage manufacturers in Mexico.⁷⁸ The three chillers recover waste heat from the baking line at the factory, converting the energy to produce chilled water for air-conditioning in the office of the factory.⁷⁹

MAYEKAWA E⁵ AMMONIA CHILLER UNIT

Mayekawa's e⁵ Chiller uses a low charge of ammonia as its refrigerant with brine as a secondary refrigerant with a capacity range from 35 kW to 1,440 kW.⁸¹ The system has a low noise level and a small physical footprint, which minimizes installation time.⁸² The e⁵ Chiller uses a Mayekawa hermetic K-series compressor with variable speed drive for optimal efficiency.⁸³



Mayekawa K-Series Compressor⁸⁰

About MYCOM Mayekawa: Established in 1924, Mayekawa manufactures compressors and thermal systems with a focus in energy efficient

natural refrigerant technology for refrigeration, air-conditioning, and heating applications.⁸⁴ The company has locations throughout North America, Europe, Asia, Latin America, the Middle East, and Oceania/Australia.⁸⁵

Frigadon Propylene Chillers (Europe, U.S.)

Swedish-based manufacturer Frigadon developed a range of propylene-based chillers with capacities between 29 and 208 kW for +7°C (44°F) flow for medium temperature, and 15.6kW at -8°C (18°F) and 88 kW at -31°C (-24°F) for low-temperature.⁸⁶ Additionally, the Skrewdriver' range of liquid chillers can also be suited to units beyond capacities of 1000 kW.⁸⁷ Units can be weatherproofed and used outdoors in temperatures between -20°C (-4°F) and +38°C (100°F).⁸⁸ All units have a built-in hydraulic kit complete with an inverter drive circulation pump.⁸⁹

About SRS Frigadon Chillers: SRS Frigadon Chillers specialize in developing air-cooled chillers using propylene refrigerant.⁹⁰ Frigadon installations can be found throughout a number of retailers across Germany, the UK and Ireland and the U.S., including Sainsbury's, COOP Bank, Nestle, Dunnes Stores, BP, Roche Pharmaceuticals, and Copplands Bakery.⁹¹



Frigadon Propylene Chiller⁸⁷

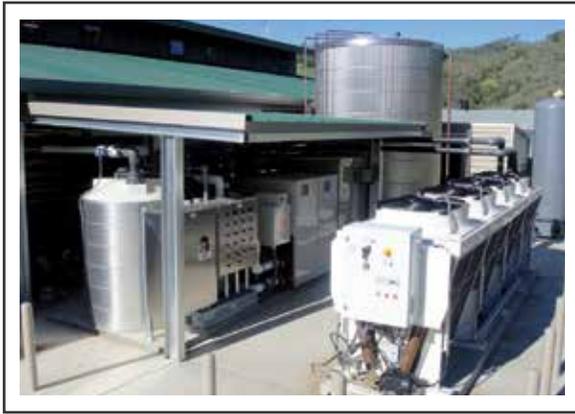
HEAT PUMPS

Mayekawa Transcritical CO₂ Heat Pumps (Global)

Mayekawa manufactures heat pumps with both air-to-water and water-to-water systems. The transcritical CO₂ Eco Cute "unimo A/W" air to water heat pump is currently a leader in the commercial/ industrial market in Japan, Asia, and Europe.⁹² The air to water system has a capacity of more than 80 kW, which Mayekawa claims is the largest in the world and can be used for large commercial applications, such as hotels, restaurants, hospitals, and food processing factories.⁹³ The system's coefficient of performance (COP) is 4.0 and when configured with cooling in addition to heating, the COP can reach as high as 8.0.⁹⁴ The COP of a heat pump is the ratio of heating or cooling provided compared to the electrical energy consumed. Higher COPs equate to lower operating costs. The system has several other environmental benefits, including low-running costs by using off-peak electricity leading to a reduction of costs of 60 percent, along with zero fuel (natural gas) consumption, which is required in traditional systems.⁹⁵

Mayekawa's Eco Cute "unimo W/W" water-to-water heat pump is larger than the air-to-water system with a heating capacity of 100 kW, which again Mayekawa claims is the largest such system in the world.⁹⁶ The water-to-water heat pump provides hot water up to 90°C (194°F) instantly due to CO₂'s high thermal capability, in addition to also chilling water quickly, all while maintaining a combined COP >5 (8 max.).⁹⁷ The system is for high water supply needs in an industrial setting and has lower operating costs than traditional heavy oil or kerosene-fired water heaters.⁹⁸

The Somerston Wine Company in Napa Valley, California installed a Mayekawa Eco Cute CO₂ heat pump for its cooling and heating processes.¹⁰⁰ By using a Mayekawa Eco Cute heat pump, the 1,115 m² (12,000 ft²) facility reduced its greenhouse gas footprint by 28 percent.¹⁰¹ The system is comprised of four main components: an Eco Cute CO₂ heat pump, a hybrid adiabatic fluid cooler that replaces the traditional cooling tower, a glycol warming system for tank and barrel room heating, and a high



Mayekawa Heat Pump at Somerston Winery⁹⁹

efficiency water-cooled glycol chiller for additional tank and barrel room cooling.¹⁰² The system has been in operation since 2010 and has reduced energy consumption by 22 percent compared to a traditional HFC-based system.¹⁰³

Mayekawa's unimo W/W water source electric heat pump was also installed at a facility owned by Verka Food Products, India's second largest milk company, to replace traditional cooling and heating equipment.¹⁰⁴ The CO₂ transcritical cycle heat pump has reduced the cost of heating and cooling in the Verka facility by 77 percent, achieving energy savings of 54 percent, in addition to reducing carbon dioxide emissions by 47 percent.¹⁰⁵ Verka Food Products plans to install the system in its other milk plants if this trial continues to produce positive results.¹⁰⁶ recovery systems.¹¹⁹

About Mycom Mayekawa: See above case study.

EcoThermics CO₂ Heat Pump at Country Maid Bakery (U.S.)

EcoThermics transcritical CO₂ heat pump has been applied at a 4,645 m² (50,000 ft²) Country Maid Bakery in Iowa, U.S.¹⁰⁷ The system provides high temperature hot water for sanitation and cold water for air-conditioning and dehumidification for food production and packaging areas.¹⁰⁸ EcoThermics heat pump boosts water temperature from 55°F to 145°F (13°C to 63°C) in one pass to tank and provides 2,200 gallons (8,328 liters) per day for 230 days a year at the facility.¹⁰⁹ Overall, the application at Country Maid has achieved

a combined cooling and heating COP of 7.2¹¹⁰, resulting in significant savings of U.S. \$3,300 per year (U.S. \$8,000 per year if run on electricity instead of natural gas).¹¹¹

EcoThermics has also developed a swash plate CO₂ compressor for commercial heat pump water heater applications.¹¹² The system is built into Multistack's HS Transcritical Heat Pump Water Heater and simultaneously provides hot water and chilled water for hospitals, hotels, and military facilities.¹¹³ The system heats water from 60°F (16°C) to 180°F (82°C) and produces chilled water at 44°F (7°C) and Multistack claims that its heat pump is 3 to 4 times more energy efficient than comparable models using fluorinated gases.¹¹⁴ End users have expressed interest in larger units and residential sized systems, and by partnering with Multistack, EcoThermics will be able to meet the needs of the U.S. market.¹¹⁵



EcoThermics CO₂ Heat Pump at Country Maid Bakery

Image courtesy of EcoThermics

About EcoThermics: EcoThermics, based in Illinois, is a developer of two families of compressors of transcritical CO₂ semi-hermetic compressors, one for original equipment manufacturers (OEM) who produce systems for refrigeration applications and the other for OEMs who produce heat pump systems.¹¹⁶ EcoThermics is applying high pressure axial piston hydraulic pump technology to compressors to achieve an operating pressure of up to 2000 psi, about five times that of traditional heat pumps.¹¹⁷

About Multistack: Multistack was founded in 1989 in Wisconsin, U.S. by three former Trane Company executives looking to take over the North American sales, marketing, engineering, and product support of an Australian-invented modular water chiller.¹¹⁸ In addition to producing modular chillers, Multistack manufactures heat pumps and heat recovery systems.¹¹⁹

About Country Maid Bakery: Country Maid Bakery has been producing pastries since 1991 and is a small commercial bakery based in Iowa, U.S.¹²⁰ Country Maid also services and supports over 65 independent dealerships providing them with products, training opportunities, marketing and sales support, IT and network support, etc.¹²¹

Mitsubishi Heavy Industries Europe CO₂ Heat Pump (Europe)



Mitsubishi's Q-ton air-to-water CO₂ heat pump has a COP of 4.3 and can be installed in hotels, care homes, leisure centers, and other building applications.¹²² The Q-ton has the ability to maintain high capacity, particularly in cold conditions and has a capacity of 30 kW, generating hot water up to 90°C (194°F).¹²³ The system can maintain 100 percent capacity even when temperatures reach -7°C (19°F), and when temperatures reach -25°C (-13°F) the

system is still capable of providing 90°C (194°F) hot water while maintaining a COP of more than 2.3, which outperforms COP's of traditional combustion boilers.¹²⁵ Other conventional products are hindered by such low temperatures and deliver inadequate performance with low energy efficiency, but the Q-ton maintains high energy efficiency when operating in freezing temperatures.¹²⁶

Mitsubishi CO₂ Heat Pump¹²⁴

About Mitsubishi Heavy Industries Europe:

Mitsubishi Heavy Industries Europe develops refrigeration and air-conditioning systems and focuses on using CO₂ as a refrigerant.¹²⁷

Hydrocarbon Chiller and Heat Pump Installed at Hospital (Denmark)

The Aarhus University Hospital Skejby in Denmark retrofitted its HCFC-22 chiller system in 2003 with hydrocarbon chillers and in 2010 the hospital installed two Johnson Control's hydrocarbon heat pumps.¹²⁸ The hospital has a total of 15 chillers used in multiple systems. The larger chiller system uses nine air-cooled propane (HC-290) chillers that each have cooling capacity of 250 kW, a COP of 4.5, and around 210 kg of propane refrigerant, delivering a propylene glycol/water solution at 9°C (48°F).¹²⁹ The two heat pumps run on about 80 kg of isobutane (HC-600a) refrigerant with a total heating capacity of 450 kW and cooling capacity of 325 kW.¹³⁰

About Johnson Controls: See Industrial Refrigeration section.

Enex CO₂ Heat Pumps (Europe)

Enex CO₂ heat pumps can be applied in commercial and industrial settings wherever large quantities of hot water are needed and/or large peaks of absorption are present, which makes the systems ideal for restaurants, hotels, canteens, laundries, residential complex, sports centers, hospitals, agrifood industry, and gyms.¹³¹

The system is a plug and play unit with two different versions, air-water and water-water, as options.¹³² The Enex heat pump is designed to produce water up to 90°C (194°F) and quantities of 5,000 liters (1,321 gallons) to 15,000 liters (3,963 gallons) per day.¹³³

About Enex: See Commercial Refrigeration Section.



Enex CO₂ Heat Pumps¹³¹

Image courtesy of Enex

Rainbow Chicken Ammonia Heat Pump Installation (South Africa)

Rainbow Chicken's P1 Plant in Hammarsdale, KwaZulu-Natal, South Africa installed an ammonia heat pump that harnesses heat generated by ammonia compressors to produce hot water in the processing plant.¹³⁴ The ammonia heat pump replaced an electrode boiler in an existing system and has reportedly realized 90 percent energy savings, exceeding the 85 percent savings projected by the system supplier, Magnet Electric (Pty) Limited.¹³⁵ The system consists of a suction intercooler, six-cylinder reciprocating compressor with a variable speed drive, a plate-and-shell condensing heat exchanger, and a programmable logic controller.¹³⁶ The system is expected to pay for itself in less than two years.¹³⁷



Rainbow Chicken Plant Ammonia Heat Pump¹³⁹

About Magnet Electrical: Established in 1984, Magnet Electrical supplies transformers, battery chargers, and magnetic equipment to industry customers in southern Africa.¹³⁸ Magnet Electrical manufactures all major components and products in-house.¹³⁹

NOT-IN-KIND SYSTEMS

Shandong Vicot Solar Air-Conditioning System (Global)

The Vicot solar air-conditioning system is built with four parts: a solar collector, an ammonia adsorption air-conditioning unit, an accumulator,



Vicot Solar Air-Conditioning System¹⁴⁰

and a central control system.¹⁴¹ The solar collector harnesses thermal energy and pushes oil through the system to drive the air-conditioner unit, while the accumulator acts as a storage space for excess solar energy in order to maintain operation during the night or in conditions of low-light.¹⁴² The solar-powered air-conditioning units maintain 85 percent thermal cooling conversion efficiency.¹⁴³ The cooling capacity of the Vicot's VSA system ranges from 72 kW to 504 kW and the system can be used anywhere there is adequate space for solar panel installation, such as hotels, shopping malls, office buildings, exhibition centers, airports, stadiums, and factories.¹⁴⁴ The systems are built with three functions: cooling only, heating only, and cooling and heating.¹⁴⁵ Vicot's other solar model, the VSB solar air-conditioning system, is comprised of solar panels, a Lithium Bromide (brine) adsorption chiller, an ammonia adsorption heat pump, an accumulator and a central control system with cooling capacity of 300 kW to 2000 kW.¹⁴⁶ Shandong reports that based on energy and maintenance savings, the system's initial investment payback period is 3.5 years.¹⁴⁷

About Shandong Vicot Air Conditioning Co., Ltd.:

Vicot Group specializes in research and development, production, sales, and services of renewable energy products. Its production base is located in Dezhou, China covering about 150,000 m² (1.6 million ft²) with annual yields of more than 100,000 electrical air-conditioning units, 10,000 gas fired air-conditioning units, and 200,000 m² (2.15

million ft²) of solar panel collectors.¹⁴⁸ The company focuses on solar energy, geothermal energy, and other renewables in cooling, heating and domestic hot water systems. Vicot has also developed HFC-free chillers and heat pumps and its systems have been installed throughout China, including an installation for the Beijing Air Force 2nd Division.¹⁴⁹ Vicot's products can be purchased throughout the world with its largest markets being China, Africa, the Middle East and Eastern Europe.¹⁵⁰

DEMA Solar Air-Conditioning System (U.S.)

In 2011, the U.S. Department of Emergency and Military Affairs (DEMA) and the Salt River Project installed a solar air-conditioning system to cool a 5,200 m² (55,970 ft²) eco-building at the Arizona National Guard Papago Park Military Reservation in Phoenix, Arizona.¹⁵² The system consists of solar panels that provide the heat source to drive a 226 tonnes adsorption chiller.¹⁵³ The hot water provided is used by the chiller to evaporate the water under a vacuum to produce cold water, which is then piped to the air handler resulting in cold air being blown throughout the building.¹⁵⁴ Two similar systems were installed in Arizona Public Service buildings, which have reportedly reduced the overall electrical consumption of the building by 25 percent.¹⁵⁵



Solar Air-Conditioning at U.S. National Guard Building¹⁵¹

AC-Sun Solar Powered H₂O-based Air-Conditioners (Denmark)

AC Sun solar air-conditioners use water as the refrigerant in a closed circuit in combination with low-pressure vacuumed turbines.¹⁵⁶ The system consists of both a driving and cooling circuit, in addition to a condenser, evaporator, heat exchanger, compressor, and expander.¹⁵⁷ In 2013, the company entered an 'on-site test' phase with its patented technology consisting of low turbines and water-based refrigerant in combination with the solar powered charge.¹⁵⁸ AC-Sun has reported that the systems save 90 percent over those using electrical power, and, result in an 85 percent reduction in carbon emissions.¹⁵⁹ Steam generated by solar heat and waste heat is used to power the turbine. After the steam is directed into the expander flow, it eventually reaches the condenser, where condensed water is then pumped back into the buffer tank.¹⁶⁰



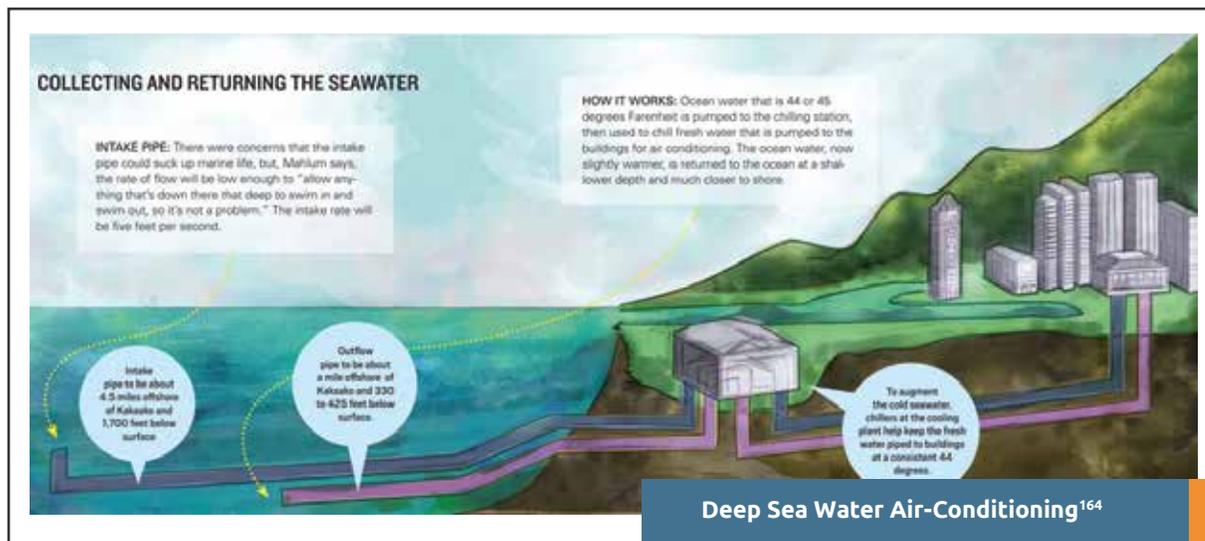
AC-Sun Turbine Assembly

Image courtesy of Shecco

About AC-Sun: AC-Sun was established in Denmark in 2005 and uses water-based refrigeration technology that is HFC-free.¹⁶¹ The technology has been widely patented throughout the world.¹⁶² Waste heat from the cooling systems can also be used for other heating purposes, such as swimming pools.¹⁶³

Deep Sea Water Air-Conditioning (U.S.)

The deep sea water air-conditioning system will provide air-conditioning to approximately 40 large commercial buildings in downtown Honolulu, Hawaii.¹⁶⁵ The deep sea water system will provide 44°F (6°C) water to a district cooling plant that exchanges heat with a freshwater stream increasing the sea water temperature by 10°F (5.5°C), which is then sent to each building's existing chilled water air-conditioning system.¹⁶⁶ The system will have a cooling capacity of 22



tonnes and with potential to cool up to 40 percent of the urban area on the island of Oahu.¹⁶⁷ The system is expected to reduce energy consumption by up to 75 percent and decrease carbon dioxide emissions by about 76,200 tonnes per year.¹⁶⁸ The system will save an estimated 77 million kW annually, which is enough to power more than 10,000 homes annually and eliminate 178,000 barrels of oil a year.¹⁶⁹ Honolulu Seawater Air Conditioning LLC, Makai Ocean Engineering, and Frank Coluccio Construction Company are the developers of the project.¹⁷⁰

About Honolulu Seawater Air Conditioning LLC: Honolulu Seawater Air-Conditioning, headquartered in Honolulu, Hawaii, was founded by Ever-Green Energy LLC of Saint Paul, Minnesota to develop seawater air-conditioning projects in Hawaii.¹⁷¹

About Makai Ocean Engineering: Headquartered in Kailua, Hawaii, Makai Ocean Engineering was founded in 1973 as a diversified ocean engineering company focused on providing design and development services to both foreign and domestic clients.¹⁷² Makai works on ocean based projects, including renewable energy, large underwater pipelines, software for planning, simulation, installation, and recovery of submarine cables and arrays, and software for visualizing scientific 4D/5D data.¹⁷³ Makai has been part of several deep sea water and lake water air-conditioning projects, including lake source systems in Toronto, Canada (52,600 tonnes), Ithaca, New York (18,140 tonnes),

as well as a Seawater Systems in Kona, Hawaii (27 to 45 tonnes), Bora Bora, French Polynesia (408 tonnes), and Curacao, Caribbean (2720 tonnes).¹⁷⁴

About Frank Coluccio Construction Company: Frank Coluccio Construction Company is based in Seattle, Washington and was founded in 1953.¹⁷⁵ The company is one of the largest underground utility contractors in the Pacific Northwest United States.¹⁷⁶

Deep Sea Water Air-Conditioning (Mauritius)

In December 2013, the Sustainable Energy Fund for Africa (SEFA) approved a U.S. \$1 million project preparation grant for the development and installation of a sea water air-conditioning system developed by Sotravic Limited.¹⁷⁷ The system will contribute to an annual reduction of about 36,287 tonnes of CO₂ emissions, in addition to significant cost and energy savings, while at the same time creating jobs and new business opportunities.¹⁷⁸ The project will be the first of its kind in Africa and will be looked at as a demonstration project for coastal cities throughout the continent and the world.¹⁷⁹ The project consists of a system that pumps cold water from deep (1,000 m) in the Indian Ocean and utilizes the cool, 5°C (41°F), deep sea water for air-conditioning by sending the cool water through heat exchangers at a cooling station supplying chilled water to target buildings located nearby.¹⁸⁰ The 4 MW system will displace the traditional air-conditioning systems currently used in buildings,

which as of now consume nearly 30 MW of electricity.¹⁸¹ For an island that harnesses most of its power from fossil fuels, such a dramatic reduction in energy use could reduce Mauritius' dependence on fossil fuels and save nearly U.S. \$6.7 million currently paid annually for oil imports.¹⁸²

About Sotravic Limited: Sotravic, headquartered in La Tour Koenig, Mauritius, was founded in 1986 and is a privately owned Mauritian construction company that operates in Tanzania, Madagascar, Seychelles, Reunion, Rodrigues, as well as Mauritius.¹⁸³ Sotravic specializes in pipeline construction for potable water mains, irrigation, and sewers.¹⁸⁴

Cornell University Lake Source Cooling (U.S.)

In 2000, Cornell University in New York upgraded its old campus chiller system that used chlorofluorocarbons to a lake source cooling system, which utilizes the deep cool waters of a nearby lake.¹⁸⁵ The 18,437 tonnes system¹⁸⁶ saves the campus an average of 25,000,000 kWh per year resulting in an 86 percent reduction in energy for cooling compared to traditional cooling methods.¹⁸⁷ The system transfers the heat from campus-chilled water to the lake water through heat exchangers.¹⁸⁸ The system is designed to last 75 to 100 years, which is over twice the typical life of chillers.¹⁸⁹ The lake source cooling system is highly cost-effective



Lake Source Cooling System at Cornell¹⁸⁸

due to its energy efficiency improvements and long life.¹⁹⁰ Makai Engineering also helped in the installation of Cornell's lake source system.

About Makai Engineering: See Honolulu Deep Sea Water Air-Conditioning case study.

MOBILE AIR-CONDITIONING CO₂ Air-Conditioning Units in U.S. Army Humvee Fleet (U.S.)

In the 1990s, the U.S. Army made research and development of air-conditioning units in its mobile fleet a priority. HFC-134a was the primary refrigerant used in its fleet, but due to environmental concerns, the U.S. Army has begun to transition to CO₂ for its refrigerant of choice.¹⁹¹ Significant advantages were found in CO₂ as a refrigerant such as: low global warming potential of 1 compared to 1,300 for HFC-134a, U.S. \$0.30/lb compared to U.S. \$4.00/lb for HFC-134a, no need for EPA-required refrigerant recovery and recycling equipment and special training, capacity improvements ranging from 25 to 50 percent, lower evaporator outlet temperatures of -6°C to -12°C (10 to 20°F) and a 50 to 100 percent reduction in temperature pull-down time.¹⁹²

ClimateWell Heat-driven Air-Conditioning for Trucks & Vehicles (Europe)

ClimateWell's air-conditioning system consists of three components: the Reactor, which contains a salt solution and is connected to a heat source during charging; the Condenser, which condenses vapor from the reactor during charging; and the Evaporator, which evaporates liquid from the condenser resulting in cooled air that is used for air-conditioning.¹⁹³ The system does not require a compressor, therefore there is no need for a refrigerant and the system runs only with heat, water and glycol (for freeze protection).¹⁹⁴ ClimateWell's system is ideal for trucks (semis and lorries), buses, recreational vehicles and construction equipment, as it enables air-conditioning while the vehicle's engine is not running.¹⁹⁵ Typically, mobile air-conditioning systems require the vehicle to be idling in order to provide cooling or heating, but ClimateWell's



ClimateWell's Heat-driven AC System
Image courtesy of ClimateWell



ClimateWell Technology
Image courtesy of ClimateWell

technology delivers air-conditioning directly from energy provided by the vehicle's fuel or from the engine waste heat (while driving).¹⁹⁶ The vehicles fuel supply (diesel) or the engine's waste heat, heats the reactor (wet salt), which induces condensation of the water in the wet salt, the condensed water in the condenser tank is then chemically attracted and drawn back to the reactor (dry salt); the evaporation that occurs during this process provides cooling.¹⁹⁷ With this technology, ClimateWell's system has potential to reduce fuel costs used for cabin comfort by up to 90 percent.¹⁹⁸

Placement of the unit is flexible and the system can be retrofitted to existing vehicles, in addition to new builds.¹⁹⁹

About ClimateWell: ClimateWell was founded in 2001 and manufactures heating and cooling technologies.²⁰⁰ ClimateWell's systems have been applied in single-family homes, housing projects, hotels, offices, shopping malls, hospitals, and other industrial applications.²⁰¹ ClimateWell markets its products globally and is headquartered in Sweden, has a research laboratory in Finland,

and a production plant in Spain.²⁰²

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APPENDICES

LIST OF CONTRACTORS AND HFC-FREE MANUFACTURERS



ACRONYMS

- BAU** - Business as Usual
- CFC** - chlorofluorocarbon
- CO₂e** - Carbon Dioxide Equivalent
- COP** - Coefficient of Performance
- GHG** - Greenhouse Gas
- GWP** - Global Warming Potential
- HC** - Hydrocarbon
- HCFC** - hydrochlorofluorocarbon
- HFC** - Hydrofluorocarbon
- HVAC** - Heating, Ventilation and Air-conditioning
- Kg** - Kilogram
- kW** - Kilowatt
- kW/h** - Kilowatt per hour
- LED** - Light-Emitting Diode
- MW** - Megawatt
- ODP** - Ozone Depleting Potential
- OEM** - Original Equipment Manufacturers
- tCO₂e** - Tonnes of Carbon Dioxide Equivalent

DESIGN & CONSTRUCTION CONTRACTORS

Manufacturer	Specialty	Location	Service Area	Website
A1 Refrigeration	Refrigeration and AC building service solutions to commercial, retail, and industrial applications	UK	UK	http://www.a1refrigeration.co.uk/index.php/home-page-1
CTA Group	Integrated design and engineering solutions for refrigeration systems	U.S.	North and South America	http://www.ctagroup.com/cta-services/
Epta Group	Design, production, and installation of custom commercial refrigeration systems	Italy	Europe	http://www.eptarefrigeration.com/
Falkenstein	Architecture, structural engineering, technology, project control	Austria, Brazil, Bulgaria	Europe, Brazil	http://www.falkenstein.de/
Makai Ocean Engineering	Design and development services for ocean engineering projects	U.S.	U.S.	http://www.makai.com/
Plotter & Racks	Offers services in industrial and commercial refrigeration projects	Brazil	Brazil	http://plotter-racks.com.br/
Honolulu Seawater Air Conditioning (Ever-Green Energy)	Developer of seawater AC projects in Hawaii	U.S.	U.S.	http://honoluluswac.com/index.html
Sotravic Limited	Pipeline construction for seawater AC projects	Mauritius	Tanzania, Madagascar, Seychelles, Reunion, Rodrigues, Mauritius	http://www.sotravic.net/

COMPRESSOR & COMPONENT MANUFACTURERS

Manufacturer	Products/Specialty	Manufacturing Location	Distribution Area	Website
Baltimore Aircoil Company	Manufacturer of evaporative heat transfer and thermal energy management equipment	North America, South Africa, Japan, Europe, China, Malaysia, UAE, India, Russia, South Korea	Global	http://www.baltimoreaircoil.com/english/
Bitzer Company	Manufacturer of compressors	Germany, China, U.S., Brazil	Global	http://www.bitzer.de/eng/Company
Carel	Manufacturer of humidification and control systems in the HVAC&R market	Italy, China, Brazil, U.S.	Global	http://www.carel.com/carelcom/web/eng/home.jsp
Danfoss	Refrigeration & AC controls, power electronics, heating solutions, commercial compressors, and district energy	North America, Europe, China, Brazil	Global	http://www.danfoss.com/
Dorin	Manufacturer of compressors	Italy	Global	http://www.dorin.com/
EcoThermics	Manufacturer of transcritical CO ₂ compressors for refrigeration applications and heat pumps	U.S.	U.S.	http://www.ecothermics.com/index.shtml
Embraco	Hydrocarbon compressors, condensing units, and electronic controls	Brazil, China, Slovakia, Italy	Global	http://www.embraco.com/default.aspx?tabid=40
Emerson Climate Technologies	Manufacturer of domestic, industrial, and commercial refrigeration and air-conditioning systems and components	Global	Global	http://www.emersonclimate.com/en-us/Pages/default.aspx
Frascold	Manufacturer of compressors	Italy	Europe	http://www.frascold.it/eindex.htm
GEA Grasso	Manufacturer of compressors and chillers	Europe, U.S., China	Global	http://www.grasso.nl/EN-US/Pages/default.aspx
Mayekawa (Mycom)	Manufacturer of compressors, cooling systems, heat pumps	North America, South America, Europe, Asia, Middle East, Australia	Global	http://www.mayekawa.com/
Tecumseh Products Company	Manufacturer of compressors and condensing units	U.S., Canada, Mexico	Global	http://www.tecumseh.com/en/united-states

SYSTEM MANUFACTURERS

Manufacturer	Products/Specialty	Manufacturing Location	Distribution Area	Website
AC-Sun	Develops and manufactures solar thermal AC systems	Denmark	Europe	http://www.ac-sun.com/
Advansor A/S (Hill Phoenix)	Industrial/commercial refrigeration display cases, walk-ins, specialty systems, and refrigeration and power systems (CO ₂ transcritical, cascade systems)	Europe/US -Aarhus, Denmark & Conyers, Georgia, U.S.	Europe, North America	http://www.advansor.dk/ http://www.hillphoenix.com/
Alfa Laval	Provides specialized products and engineering solutions to heat, cool, separate and transport products in the food and beverage industry	Europe (12), Asia (6), Americas (2)	Global	http://www.alfalaval.com/Pages/default.aspx
Arcelik	Household appliances	Turkey	Global	http://www.arcelik.com.tr/fridge-freezers-no-frost-refrigerator-5088-A----NFY-Refrigerator.html
Axima Refrigeration (Cofely)	Industrial and commercial refrigeration and air-conditioning	France	Global	http://www.aximaref.com/english/index_en.php
Blupura	Household appliances	Italy	Global	http://www.blupura.com/eng/index.html
Bosch	Household appliances	Singapore, U.S., Mexico, Europe	Global	http://www.bosch.us/en/us/bosch_worldwide_1/bosch-worldwide.html
Brastemp	Household appliances	Brazil	Brazil	http://viva.brastemp.com.br/
Bundgaard Koleteknik A/S	Manufacturer of chillers and heat pumps	Denmark	Europe	http://www.coolcare.dk/welcome.html
Carnot Refrigeration	Manufacturer of commercial and industrial refrigeration systems	Canada	North America	http://www.carnotrefrigeration.com/en/
Carrier	Manufacturer of commercial refrigeration	U.S., Global	Global	http://www.carrier.com/carrier/en/us/products-and-services/commercial-refrigeration/
Carrier Transicold	Manufactures equipment designed for refrigerated trucks, trailers, and containers	Global	Global	http://www.transicold.carrier.com/Carrier+Brand+Sites/Carrier+Transicold/Side+Bar+Links/Home
ClimateWell	Manufacturer of Heating and Cooling Systems	Sweden, Finland, Spain	Global	http://www.climatewell.com/index.htm
De'Longhi	Small appliance manufacturer	Italy	Europe, Asia, Australia, New Zealand, Dubai, South Africa, Brazil, Chile, U.S., Canada	http://www.delonghi.com/en-us/products/comfort/air-conditioning
Duracool	Manufactures hydrocarbon refrigerants and products	Canada	Global	http://www.duracool.com/
Dybydal Industri (DSI)	Designing and manufacturing operated and automatic plate freezers	Denmark	Global	http://www.dsi-as.com/
Enex	Designs and produces refrigeration systems and heat pumps using natural fluids	Italy	Europe	http://www.enex-ref.com/Default.aspx
Engas	Manufacturer of hydrocarbon refrigerant blends	Australia	Australia, Thailand, China, Philippines, Singapore	http://www.engas.com.au/
Frigo-Consulting	Manufacturer of commercial and industrial refrigeration systems	Switzerland, Italy	Europe	http://www.frigoconsulting.ch/de/aktuell.html
General Electric	Household appliances	Indiana, Kentucky, Tennessee, Alabama	Africa, Asia, Australia/Oceania, Europe, Middle East, Americas	http://www.geappliances.com/
Green & Cool	CO ₂ Refrigeration	Sweden	Global	http://www.greenandcool.com/en-gb/

SYSTEM MANUFACTURERS (cont.)

Manufacturer	Products/Specialty	Manufacturing Location	Distribution Area	Website
Godrej	Manufacturer of domestic appliances	India	India, Bangladesh	http://www.godrejandboyce.com/godrej/godrejandboyce/index.aspx?id=16
Gorenje	Household appliances	Slovenia, Austria, Serbia, Bosnia & Herzegovina, Czech Republic, Ukraine	Europe, Asia, Middle East, Australia, and Brazil	http://www.gorenje.com/
Gree	Manufacturer of domestic appliances	China	Global	http://www.greeac.com/
Haier	Household appliances	China, U.S.	Global	http://www.haier.com/cn/consumer/cooling/dkmbx/201307/t20130723_175581.shtml
Husmann Corporation	Manufacturer of display cases and refrigeration systems	U.S.	U.S., Mexico, Australia, New Zealand, China	http://www.husmann.com/en
Johnson Controls	Manufactures transport refrigeration systems, air-conditioning, and refrigeration systems	U.S.	Global	http://www.johnsoncontrols.com/
Midea	Household appliances	China, Vietnam, Belarus, Egypt, Brazil, Argentina, India	Global	http://www.midea.com/global/
Mitsubishi Heavy Industries Europe	Manufactures refrigeration and air-conditioning systems	Europe	Europe	http://www.mhia.com/
Multistack	Manufactures chillers, heat pumps, and heat recovery systems	U.S.	North America	http://www.multistack.com/Home.aspx
natureFridge (ecoFridge Production Company)	Manufacturer of transport refrigeration systems	Ukraine	Global	http://naturefridge.com/
Panasonic	Manufacturer of CO ₂ outdoor condensing units and compressors	Global	Global	http://industrial.panasonic.com/ww/products_e/product_cat2/ADC6000_e/ADC6000_e/ADC6000_co2_d01.html
Pioneer International	Manufacturer of domestic and commercial air-conditioners	Australia	Global	http://pioneerair.com.au/major-air-conditioning-brands/
Shandong Vicot	Research and development, production, sales, and services of solar AC systems	China	China	http://www.vicot.com.cn/english/Index.asp
SRS Frigadon	Manufactures air-cooled chillers and heat exchangers	Sweden	Europe	http://www.srs-frigadon.com/
Star Refrigeration	Industrial and commercial refrigeration	UK	Europe, U.S.	http://www.star-ref.co.uk/star/
Systems LMP	Manufacturer of commercial and industrial refrigeration systems	Canada	North America	http://www.lmpinc.ca/
The Fridge Factory	Domestic and commercial refrigeration	Swaziland	South Africa	http://www.thefridgefactory.com/
Thermo King (Ingersoll Rand)	Manufacturer of transport refrigeration systems	U.S., China, Belgium, Spain, Ireland, Czech Republic	Global	http://www.thermoking.com/imagecenter/products/cryotech.pdf
Trane (Ingersoll Rand)	Manufacturer of heating, ventilating, and air-conditioning systems	Global	Global	http://www.trane.com/Index.aspx
True Manufacturing	Manufacturer of domestic and commercial refrigerators	U.S.	Europe, North America	http://www.truemfg.com/
Yantai Moon Group	Research and development and manufacturer of large/middle scale AC and refrigeration equipment	China	China, Vietnam, Hongkong, Bangladesh, India, Iran, Indonesia, Malaysia, Myanmar, Pakistan, Philippines, Russia, Saudi Arabia, Thailand, UAE	http://www.yantaimoon.com/Enindex.asp

CONCLUSION

ALTERNATIVES TO HFCs FOR REFRIGERATION AND AIR-CONDITIONING ARE AVAILABLE NOW



As the case studies in this report illustrate, there are numerous cost-effective, safe, and proven low-GWP alternative technologies to HFC systems. These technologies are available for nearly every type of refrigeration and air-conditioning need and should be utilized industry wide.

Such technologies are not limited to specific climatic areas and are being proven and commercialized in both developed and developing countries.

Specifically in the refrigeration sector, self-contained units, rack systems, and central plant systems that rely on carbon dioxide, air, water, ammonia, hydrocarbons, or combinations of these refrigerants are being manufactured and sold around the world. Similarly, equipment using these refrigerants are being developed and commercialized within the heating, ventilation and air-conditioning (HVAC) sector for factory-sealed, single-split, multi-split, ducted, chillers, heat pumps, and mobile air conditioners. Additionally, several alternative methods and processes that do not involve chemical refrigerants (also referred to as “not-in-kind” alternatives), such as district cooling and solar-thermal water air-conditioners are delivering substantial energy savings. Rapid expansion of the market penetration of these technologies is expected as more countries take action to phase out the use of HCFCs and HFCs.

In addition to reducing direct GHG emissions, this digest shows that using HFC-free alternatives offers the co-benefit of reducing energy consumption, including in high ambient temperatures. Additionally, as these technologies become more widely adopted, their associated costs are decreasing and the servicing infrastructure is expanding. Highly efficient product designs are currently available using natural refrigerants, which are the next generation of refrigeration and air-conditioning equipment delivering both energy savings and direct climate benefits from the elimination of HCFCs and HFCs.

Given the great risk that HFCs pose to the global climate, actions are being taken around the world to transition directly from HCFCs to low-GWP technologies through HFC phase-downs at national levels and bans of certain HFCs in some major sectors. As a result, cooling technology using HFCs are becoming dead-end technologies with an extremely limited shelf life. Countries planning to phase out ozone depleting substances, and companies exporting to the countries that already have or are planning regulation of HFCs, such as the EU, Japan and the U.S. among others, are rapidly transitioning and developing natural HFC-free technologies, in order to remain competitive in this new multi-billion dollar worldwide market. Going HFC-free in these sectors is no longer a challenge, but an opportunity not to be missed.



... using HFC-free alternatives has demonstrated greater energy efficiency, including cases in high ambient temperatures.



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